SYNTHESIS OF VULNERABILITY ANALYSIS STUDIES

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SYNTHESIS OF VULNERABILITY ASSESSMENTS

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ABSTRACT

Existing vulnerability analyses at a local, national and global level (The Global Vulnerability Analysis or GVA) are reviewed, synthesized and compared to establish common findings and validate the GVA. This comprises a `bottom-up' approach from the case studies and a `top-down' approach from the GVA. The GVA was developed using the Common Methodology and can be meaningfully compared with the country studies, assuming that its spatial limitations are considered. (Short summaries of the local and country case studies are given in Appendix 1).

To date, 22 country case studies and 8 local area case studies have produced quantitative data related to vulnerability to a one-meter rise in sea level in 100 years and no development (present population and economic activity). Aggregation of these studies under these scenarios, and assuming no responses, shows that nearly 180 million people would be affected, assets presently worth over US $1,100 billion would be lost, and over 150,000 km^2 of land could be lost, including 62,000 km^2 of coastal wetlands. Small island states stand out as being particularly vulnerable from most perspectives. Coastal wetlands also appear to be highly vulnerable. Comparison between the GVA and the country studies demonstrates that the GVA produces reasonable estimates at the regional scale for population affected (by storm surge flooding), wetlands at loss and basic protection costs (maintaining existing standards of protection). There is insufficient data to check the updated (1993) protection costs which include regional hydraulics. However, this likely serves as a useful lower bound of realistic response costs for sea level rise.

Several improvements to future vulnerability assessments would be useful. These include examining a wider range of response options between total retreat and total protection. In addition, an improved assessment of the vulnerability of coastal wetlands to sea-level rise should be encouraged. This includes modeling both the non-linear response of coastal wetlands to sea-level rise and the likely upland to wetland conversion which may occur as sea level rises. Lastly, the interaction of river flooding with sea level rise requires better evaluation in low-lying coastal areas.

INTRODUCTION

Studies on the vulnerability of coastal areas, within the framework of IPCC CZMS, have been conducted as one of three types:

Local area study
With respect to a local area of a coastal zone, from less than 10 to several hundreds of kilometers along the coastline within one country;

Country study
With respect to the entire coastal zone of one country;

Global study
With respect to the coastal zones of the entire world.

At the beginning of January 1994, 8 local area studies and 30 country studies were partly available for this aggregation analysis and the Global Vulnerability Analysis (1993 version) was available. Table 1 summarizes the studies and their type.

Table 1. Inventory Of Case Studies

COUNTRY	STUDY TYPE	REMARKS
Antigua	Country study	excludes Barbuda Island
Argentina	Country study	
Australia	Local study areas	Geographe Bay and the Cocos Islands
Bangladesh	Country study	
Belize	Country study	preliminary results
Benin	Country study	
Brazil	Country study	largely qualitative study
China	Country study	preliminary estimates, plus case studies
Cuba	Country study	largely qualitative study
Egypt	Country study	emphasis on the Nile Delta
England and Wales	Local study areas	East Anglia and South Coast
France	Local study area	Rochefort sur Mer
Germany	Country study	preliminary results
Ghana	Country study	qualitative study
Guyana	Country study	
India	Local study area	Orissa and West Bengal
Japan	Country study	emphasis on Tokyo Bay area
Kiribati	Country study	Betio Island
Malaysia	Country study	largely qualitative study
Maldives	Country study	qualitative study
Marshall Islands	Country study	Majuro Atoll
Mexico	Local study area	Rio Lagartos, Yucatán
Moorea Island	Country study	qualitative study
Netherlands	Country study	
Nicaragua	Country study	preliminary study
Nigeria	Country study	
Peru	Country study	qualitative study
Poland	Country study	
Senegal	Country study	
Seychelles	Country study	qualitative study
St Kitts-Nevis	Country study	

Table 1 Continued

Tonga	Country study	Tongatapu Island
Turkmenistan	Country study	qualitative study (Caspian Sea)
USA	Country study	land loss and protection costs
Uruguay	Country study	
Venezuela	Country study	
Vietnam	Local study area	Red River delta (preliminary results)
Global Vulnerability Analysis GVA)	Global study (4 factors)	Population at Risk Wetlands at Loss Rice at Change Protection Costs

As studies continue to appear or be updated, it is useful to review these results on a regular basis, including their aggregation, with the aim of identifying common findings and trends. In addition, as case study findings become known, it is important to compare them with the findings of global studies of the Global Vulnerability Analysis (GVA). This allows extrapolation and aggregation of case study values to regional and global scales. These exercises can be seen as a combination of a `bottom-up' approach from the case studies, and a `top-down' approach from the GVA. A meaningful and validated GVA is useful to provide a reference and context for local, country and regional case studies. Both the case studies and the GVA are performed along the lines of the Common Methodology. The first GVA is presented in the IPCC CZMS 1990 report. It focused on basic protection costs. The GVA was extended to consider the impact of an accelerated rise in sea level and development for the world coast (179 coastal countries) on population, coastal wetlands and rice production. It also extends the first GVA and considers protection costs for people at risk.

This paper extends a similar preliminary analysis undertaken as part of the Margarita Island Workshop to include more complete results and new studies. The Common Methodology and Global Vulnerability Analysis are briefly considered. Then the suitable studies are synthesized and aggregated and common themes and aggregated results considered. These results are then compared with the GVA. Brief summaries of all the available case studies are attached in Appendix 1.

2. THE COMMON METHODOLOGY

In collaboration with experts from various international bodies, in September 1991, the Coastal Zone Management Subgroup (CZMS) published "The Seven Steps for the Assessment of the Vulnerability of Coastal Areas to Sea Level Rise - A Common Methodology" (Tables 2 and 2(a)). A second revision was released in the 1992 in *Global Climate Change and the Rising Challenge of the Sea*, accompanied by techniques to inventory and delineate areas vulnerable to sea level rise. Vulnerability is not merely the identification of resources at risk. The common methodology defines *vulnerability* as a nation's ability to cope with the consequences of an acceleration in sea level rise and other coastal impacts of global climate change.

The objectives of the methodology are to provide a framework to:

- identify and assess physical, ecological, and socio-economic vulnerabilities to accelerated sea level rise and other coastal impacts of global climate change;
- understand how development and other socio-economic factors affect vulnerability;
- clarity how possible responses can mitigate vulnerability, and assess their residual effects; and
- evaluate a country's capacity for implementing a response within a broad coastal zone management framework.

In assessing vulnerability to sea level rise, the common methodology considers the potential impacts on population, on economic, ecological, and social assets, and on agricultural production. It uses present sea level and (global) rises of 0.3 and 1.0 meters by the year 2100. These two scenarios approximate the low and high estimates of the IPCC 1990 Scientific Assessment. (The high estimate, as implied by the IPCC 1992 Update, would be a 0.9 meter rise by the year 2100). The common methodology includes three scenario variables: global climate change factors, local development factors, and response options. It considers national or local development by extrapolating 30 years from the present situation. The common methodology strongly encourages coastal nations to consider a full range of response options - and at a minimum, the extreme options of retreat and total protection.

The common methodology is designed to address the effects of an acceleration in sea level rise as a result of human-induced climate change. It should be kept in mind, however, that sea level can rise or fall either as a result of local geotectonic subsidence or uplift, or as a result of human activities, such as the over-exploitation of ground water and hydrocarbon extraction. Construction of dams or protective structures that reduce sediment loads reaching deltas and shorelines also have important implications for coastline dynamics. In many coastal areas, these processes and activities are significant. If the vertical movement of the land is known, then a local (or relative) sea-level scenario, or scenarios, can be calculated from the global scenarios defined in the common methodology. Sediment deficits should also be evaluated.

It should also be remembered that coastal populations are rapidly expanding worldwide, particularly in many developing nations. Half of the world's present population is thought to live within 60 km of a coast, equivalent to the entire global population of the 1950's. Problems associated with human-related activities are likely to exacerbate the problems expected from sea level rise.

The analysis conducted under this framework can show the long-term consequences of alternate actions and implementation dates. Nevertheless, as the Margarita Island Report notes, the trade-offs between current costs and future benefits, or between safety, environment, and monetary damages must be made through the political process, not through a technical assessment. The goal of the common methodology, and vulnerability assessment in general, is to provide a link between research, monitoring and the policy making process and hence assist policy-makers to make informed decisions.

3. GLOBAL VULNERABILITY ANALYSIS (GVA)

One of the tasks of the CZMS is to provide a world-wide estimate of socio-economic and ecological implications of accelerated sea level rise. As part of this effort a Global Vulnerability Assessment (GVA) was conducted. In consideration of data and modeling constraints, among others, the GVA at this stage is limited to four elements of the coastal zone and accompanying impacts:

1. *population at risk* (i.e. the number of people subject to regular flooding) on a global scale;
2. *wetlands at loss* (i.e. the ecologically valuable coastal wetland area under a serious threat of loss) on a global scale;
3. *rice production at change* (i.e. the changes in coastal rice yields due to less favorable conditions due to accelerated sea level rise) in South, South-east and East Asia;
4. *protection cost* updates of the estimates in the 1990 IPCC CZMS report.

While they are limited, these elements embrace factors concerning people, land use, the environment and the economy, and allow investigation of the consequences of development and the limits of adaptation. It should be stressed that the underlying data and the assumptions about physical and socio-economic boundary conditions and physical processes, limit the accuracy of the country-by-country results in the GVA. It is therefore best to aggregate the results to a higher aggregation level to reduce the random part of the inaccuracy to an acceptable level.

Table 2 Seven Steps of the Common Methodology

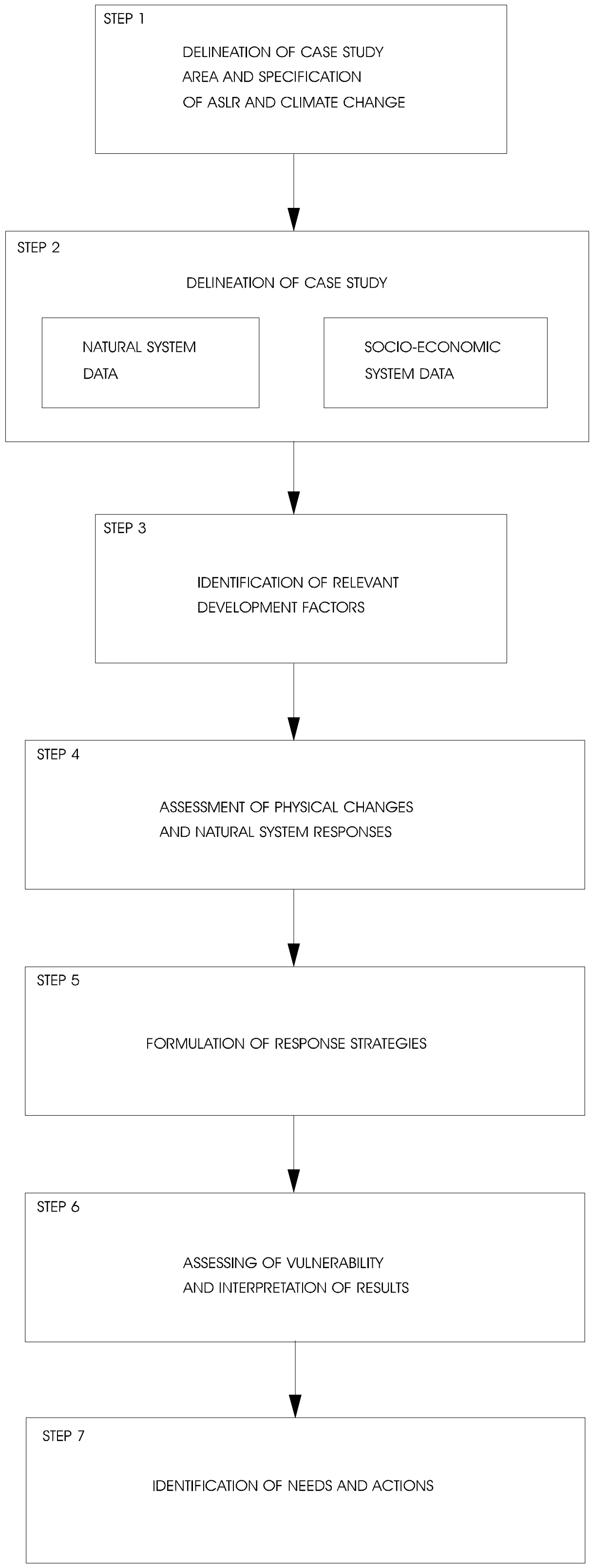


Table 2(a). Status Of Case Studies With Respect To The Common Methodology

	steps 1	2	3	4	5	6	7
SMALL ISLANDS							
Antigua	X	X	0	X	X:qt	X	X
Kiribati	X	X	X	X	X	X	X
Nevis	X	X	0	X	X:qt	X	X
Maldives	ql	ql	ql	ql	ql	ql	ql
Marshall Islands	X	X	X	X	X	X	X
Mauritius	X	X	0	X	0	0	0
Moorea	X	X	0	X	0	0	0
Tonga Tongatapu Is	X	X	0	X	ql	0	0
Australia Cocos Islands	X	X	0	ql	ql	ql	ql
Seychelles	X	P	0	ql	0	0	0
CONTINENTAL SHORES							
Argentina	X	X	0	Er+In	X	X	
Australia Geographe Bay	X	X	0	ql	Prot:qt	0	
France Rochefort	X	X	0	X	Prot:qt	0	
Guyana	X	X	X	X	Prot:qt	X	
India Orissa	X	X	0	X	Prot Retr	0	
Japan	X	X	0	X	X	0	
Japan Tokyo	X	X	0	X	ql	0	
Mexico Rio Lagartos	X	X	0	ql	0	0	
Nigeria	X	X	0	Er+In	X	X	
Peru	X	X	0	ql	0	0	
Poland	X	X	X	X	X	X	
Senegal	X	X	0	Er+In	X	X	
Uruguay	X	X	0	Er+In	X	X	
USA	X	P	0	0	Prot	0	
Venezuela	X	X	0	Er+In	X	X	
Benin	X	X	0	Er+In	Prot:qt	P	
Cuba	X	P	0	0	0	0	
England and Wales - East Anglia	X	X	0	X	X	X	
Germany	X	P	0	P	P	0	
Ghana	X	P	0	ql	0	0	
Belize	X	X	0	P	0	0	
Turkmenistan	X	P	0	0	0	0	
Brazil	X	P	0	0	0	0	
Malaysia	X	X	0	ql	ql	ql	
England and Wales - South coast	X	X	0	X	X	X	

Table 2(a) Continued

DELTAIC AREAS							
Bangladesh	X	X	X	X	P	P	P
China	X	0	0	X	ql	ql	0
China Bohai Bay	X	X	0	X	Acc		
					Prot	0	0
China Huanghe Delta	X	X	0	X	Acc		
					Prot	0	0
China Laizhou	X	X	0	X	Acc		
					Prot	0	0
Egypt	X	X	X	X	X	X	X
India West Bengal	X	X	0	X	Prot		
					Retr	0	0
Netherlands, the	X	X	X	X	X	X	X
Nigeria	X	X	0	Er+In	X	X	P
Vietnam Red River	P	P	0	0	0	0	0
TOTAL (per step)	45	44	8	40	34	23	18

LEGEND:

X	Fully accomplished
P	Partially available at this stage
0	Not accomplished at this stage
ql	Qualitative description given
qt	Quantitative estimate made
Acc	Accommodation response strategy analyzed
Prot	Protection response strategy analyzed
Retr	Retreat response strategy analyzed
Er	Coastal erosion impacts studied
In	Inundation impacts studied
*	Used common time frame of 2050

4. AGGREGATION OF CASE STUDY RESULTS

4.1 APPROACH TO AGGREGATION

In total 22 country case studies and 8 local area case studies were suitable for aggregation of results. In order to maximize the number of studies used in the comparison and aggregation, only results for a few selected factors were extracted from the case study reports.

Common denominators are required for aggregation purposes. The scenarios of a 1 m rise in sea level over the next 100 years and no development (present population and economic status) were the most suitable common denominators. It will be possible to consider more factors from the common methodology in future reviews as more studies become available. The IPCC 1992 Update implies that the high scenario for sea level rise by the year 2100 is 0.9 meters. Therefore, a 1 m rise in sea level provides an approximate upper bound of vulnerability to sea level rise.

The factors selected for the aggregation, the definitions adopted and some comments on the difficulties encountered in elaborating the data are summarized as follows:

Number of people affected
This factor is defined as the number of people living in the risk zone. This is the area that, in the absence of any existing sea defence will be subject to inundation or flooding at least once per 100 years with a 1 m sea level rise. Both absolute and relative values were extracted, the latter expresses the former as a percentage of the national or total local area population. In some studies, people affected was reported without defining the risk zone or the method of calculation. In other studies the number of people requiring relocation due to land loss is given. This was used as a minimum estimate of the number of people affected.

Number of people at risk
This factor is defined as the number of people affected by a 1 m sea level rise, multiplied by the probability of flooding. In general this is the probability of the failure or the overtopping of the coastal protection system. The result is a statistical estimate of the number of people who will experience flooding with a certain return period. In this analysis the probability of flooding with a return period of one year is estimated, further referred to as *annual flooding*. These figures were aggregated for the case of a 1 m sea level rise, taking into account both the present state of coastal protection systems, and an additional protection option. The number of people at risk per year was only provided in 7 studies. Most studies did not describe existing levels of protection in terms of frequency of overtopping of coastal defenses. Also, many studies did not contain water level exceedance frequency information. This is mainly due to a lack of measured data. Great care needs to be taken in the definitions used to establish the number of people at risk . The sensitivity of the number of people at risk factor for a varying definition can be seen in the case of the Netherlands. Using the Common Methodology definition, it is estimated that 24,000 people are at risk of annual flooding after a 1 m sea level rise by the present level of protection. However, if no coastal maintenance of the protection systems is assumed over the next 100 years, the integrity of the natural dune protection would be damaged by progressive erosion and the probability of failure of the protection system would increase dramatically. Then, over 3.7 million people would be at risk. This emphasizes the critical importance of a proper use of the defined factors in the Common Methodology, especially for the political crucial estimate of the *number of people at risk*.

Capital value at loss

This factor is defined as the capital value of the dry land and infrastructure that will be permanently lost by inundation or erosion due to sea level rise. This factor is aggregated as an absolute and as a relative figure, the latter expressed as a percentage of the national or study area GNP. For high relative capital value losses, the gross value may be larger than GNP, resulting in a relative figure exceeding 100%. Some studies note that they provide incomplete inventories of capital value at risk. It was not clear in many of the other case studies whether capital values at loss included infrastructure, industries, production losses etc. This means that the estimated losses should generally be considered as underestimates. Capital value at loss is reported as given in each case study, with no attempt to bring the studies to a common time frame. Given that all the studies occurred over a relatively short period (2/3 years), this is not a major limitation.

Area of land at loss

This factor is defined as the area of land (both dry land and wetland) that will be permanently inundated or eroded due to a 1 m sea level rise. This factor is aggregated as an absolute and as a relative figure - expressed as a percentage of the total national or local area. Some studies defined land loss as land subject to at least annual flooding, rather than permanent inundation and in other studies it was not clearly stated what criteria had been used. Another problem is that it is not always clear if inundation, or a combination of inundation and erosion were considered. The approaches used to define land loss are not always clearly defined. (Note that the IPCC-CZMS 1992 report considered **area of dry land at loss**. However, in certain countries, such as Senegal and Nigeria, wetland loss is large, even in terms of the national land area, and dry land loss is relatively small. Therefore, for this analysis it seems more meaningful to aggregate dry land and wetland loss. Dry land loss could be considered as an additional parameter in future analyses).

Wetlands at loss

This factor is defined as the natural areas of coastal wetlands that will be lost or dramatically changed due to a sea level rise of 1 m. Wetlands have an international recognized importance as breeding, feeding and nursing grounds for many species. They have many other important and valuable functions, depending on type and location. In many case studies the type of wetlands considered (e.g. marshes, mangroves, intertidal areas or coral reefs) was not clearly defined. The procedures used to assess the response of these systems to sea level rise is often inadequately defined. The estimates of land loss are sensitive to the approaches and assumptions made and these should be clearly stated. In addition, it is generally unstated if the potential for wetland migration (dry land to wetland conversion as sea level rises) was considered. Lastly, the potential impact of protection measures and development on the wetland areas was not clearly elaborated in many case studies.

Protection and adaptation costs

This factor is defined as the protection and other adaptation costs required to maintain a protection status (after a 1 m sea level rise) which is equivalent or better than the present design standard of the case study area. Present price levels are assumed. To allow comparison with GNP, it is assumed that the lifetime of the protection infrastructure will be 100 years. Then the annual cost is 1% of the total cost. The annual maintenance costs could be significant, but are excluded. The costs are expressed in absolute and relative figures. The former is given as total cost and the latter is expressed as a annual percentage of GNP. Various methods and assumptions to arrive at a total cost estimate were used in the different case studies, but in general the definition used here was followed. In some cases, a range of protection and adaptation costs is reported, reflecting uncertainties in how much sand will need to be pumped to maintain beaches, and the required size of seawalls. Protection and adaptation costs are reported as given in each case study, with no attempt to bring the studies to a common time frame. Given that all the studies occurred over a relatively short period (2/3 years), this is not a major limitation.

Qualitative comments
Any relevant comment or factor which was repeated in a number of studies was noted. The aggregated results are presented in Tables 3(a), 3(b) and 4.

4.2 AGGREGATION OF FINDINGS

People affected is defined in 24 case studies and amounts to nearly 180 million individuals. Nearly 80% of these people come from just two countries: 72 million in China and 71 million people (or 60% of the national population) in Bangladesh. In both cases these results consider both inundation and increased flooding. For Bangladesh, the interaction between sea level rise and river floods as well as increased precipitation are considered. Sea level rise increases river floods considerable distances inland in low-lying coastal areas. An earlier study of Bangladesh estimated that 13 million people would be displaced from their homes by a one-meter rise in sea level, demonstrating the more than fivefold increase in the people affected by considering increased flooding from rivers and storm surges. Viewing all the results, the number of people affected varies from 0.3% of the total population in Venezuela and 0.4% of the total population in Uruguay, to 100% of the population in both Kiribati and the Marshall Islands. The number of people affected in Venezuela and Uruguay represents a minimum estimate. Despite the large population affected in China, it only represents 6.5 percent of the national population. People at risk is defined in only 7 case studies, totalling about 850,000 people/yr.

Fifteen case studies give capital value at loss, with a total loss of over US $1,100 billion being estimated. This averages about 65% of the GNP of these countries. Guyana has a particularly high vulnerability with a capital value in excess of 11 times its present GNP being threatened.

Twenty-six case studies define land loss (the sum of dry land and wetland loss). The total land loss was estimated to be over 150,000 km^2. The estimated losses range from 0.05% of the national land area in Uruguay to over 80% of the national land area of the Marshall Islands. On average, the estimated loss is about 1% of the total land area of these 24 countries.

From 15 case studies, 62,000 km^2 of wetlands are estimated to be at loss. The wetland loss greatly exceeded (>10 times) the dry land loss in 3 cases: Nigeria, Senegal and Venezuela. The Uruguay study notes the limited possibility for wetland migration in most locations due to a break in slope along the Rio de la Plata. The studies of Senegal, Nigeria and Venezuela note that wetland migration could not fully replace the wetlands which are lost due to sea level rise, but are unable to quantify migration due to limited topographic and other data. The studies of Senegal and Uruguay report 100% losses of wetlands for a one-meter rise in sea level (wetland migration not evaluated). However, the studies note that total loss is unlikely and these results should be interpreted as substantial (>50%) losses. The study of the U.S.A. considered wetland migration and estimated that on average about 5,400 km^2 of dry land would be converted to wetland by a 1 m rise in sea level. Therefore, protection of all dryland areas increases net wetland losses from 49% to 66%, nationally. Lastly, the study of Malaysia found that while the coastal wetlands are vulnerable to sea level rise, direct reclamation is a much bigger threat. Based on existing trends mangroves could disappear within a decade.

Table 3 (a) Results of Case Studies - Local Area Studies - No Measures - January 1994

	People Affected		People At Risk	Capital Value At Loss		Land at Loss		Wetland at Loss
	#People * 1000	%Total	#People	Mil US$	%GNP	Km^2	%Total	Km^2
Australia (Geographe Bay)	44	-	-	-	-	-	-	-
Australia (Cocos Islands)	0.6	100	-	-	-	-	-	-
China[1] (North China Coastal Plain)	n.a.	n.a.	520,000	12,000	95	n.a.	-	-
England and Wales (East Anglia)	>54	-	-	2,000	-	-	-	-
England and Wales (South Coast)	96	-	-	5,500	-	-	-	-
France (Rochefort sur Mer)	-	-	-	-	-	5	1.2	-
India (Orissa and West Bengal)	737	1	-	500	6	4,850	-	3,250
Mexico (Rio Lagartos, Yucatan)	3	65	-	-	-	9	1.8	-
TOTAL	935		520,000	20,000		4,864		3,250

Notes
1. National results for people affected and land at loss are given in Table 3(b).

Table 3 (b). Results of Case Studies - Country Studies - No Measures - January 1994

	People Affected		People At Risk	Capital Value At Loss		Land at Loss		Wetland at Loss
	#People * 1000	%Total	#People	Mil US$	%GNP	Km^2	%Total	Km^2
COUNTRY STUDIES								
Antigua	38	50	1,900	-	-	5	1.0	3
Argentina	-	-	-	5,600[3]	6	3,400	0.1	1,100
Bangladesh	71,000	60	-	-	-	25,000	17.5	5,800
Belize	70	35	-	-	-	1,900	8.4	-
Benin	1,350	25	-	126	12	230	0.2	85
China	72,000	7	-	-	-	35,000	0.4	-
Egypt	4,700	9	30,000	59,272	204	5,800	1.0	-
Guyana	600	80	60,000	4,000	1115	2,400	1.1	500
Japan	15,400	15	-	807,000	72	2,300	0.62	-
Kiribati	9	100	-	2	8	4	12.5	-
Malaysia	-	-	-	-	-	7,000	2.1	6,000
Marshall I.	40[5]	100	20,000	175	324	9	80	-
Mauritius	6	1	-	-	-	10	0.5	-
Netherlands	10,000	67	24,000	186,000	69	2,165	5.9	642
Nigeria	3,200[2]	4	-	18,000[3]	52	18,600	2.0	16,000
Poland	235	1	196,400	24,000	24	1,700	0.5	36
Senegal	>110[2]	>1	-	700	14	6,100	3.1	6,000
St Kitts-Nevis	-	-	-	-	-	1	1.4	1
Tonga	30	47	-	-	-	7	2.9	-
Uruguay	13[2]	<1	-	1,800[3]	26	96	0.1	23
U.S.A.	-	-	-	-	-	28,400[4]	0.3	17,000
Venezuela	56[2]	<1	-	350[3]	1	5,700	0.6	5,600
SUB-TOTAL	178,857		332,300	1,107,025		145,827		58,790
TOTAL (LOCAL STUDIES) (from Table 2)	935		520,000	20,000		4,864		3,250
TOTAL	179,792		852,300	1,127,025		150,691		62,040

Notes:
1. Results for people affected already counted in national assessment above.
2. Minimum estimates - number reflects estimated people displaced
3. Minimum estimates - capital value at loss does not include ports
4. 17,000 km^2 of dry land is lost, but about 5,400 km^2 are converted to coastal wetlands.
5. National estimate.

Table 4. Results of Case Studies - With Measures - January 1994

	People At Risk	Protection/Adaptation Costs, 100 Years	Protection/Adaptation Costs/Year
	# People	Mil US$	% GNP
Antigua	7,700	76	0.32
Argentina	-	1,800/3,300	0.02/0.04
Bangladesh	-	>1,000[2]	>0.06
Benin	-	>430	>0.41
Egypt[1]	120,000	13,133	0.45
Guyana	-	200	0.26
Japan	-	>200,000	>0.15
Kiribati	-	3	0.10
Marshall I.	2,000	>380	>7.04
Netherlands	1,200	12,286	0.05
Nigeria	-	1,400/1,800	0.04/0.05
Poland	9,900	1,500	0.02
St Kitts-Nevis	-	53	2.65
Senegal	-	1,000/2,200	0.21/0.40
Uruguay	-	1,000/3,800	0.12/0.46
U.S.A	-	>143,000	>0.03
Venezuela	-	1,700/2,600	0.03/0.04
SUB-TOTAL	140,800	>378,961/385,761	
LOCAL AREA STUDIES`			
China (North China Coastal Plain)	130,000	500	0.04
France (Rochefort sur Mer)	-	135	-
India (Orissa and West Bengal)	-	310	0.04
Mexico (Rio Lagartos, Yucatan)	-	6	-
TOTAL	270,800	>379,912/386,712	

Notes: 1. Results for Egypt include development scenarios.
2. Only gives protection against a 1 in 20 year event, and no other adaptation.

Twenty case studies give protection and adaptation costs. The aggregated and accumulated costs are at least US $380 billion. This cost is dominated by Japan and the U.S.A. whose protection costs constitute 53% and 38% of the total, respectively. The annual costs, defined as the percentage of GNP, varies from 0.02% for Poland to >7% for The Marshall Islands. The likely minimum nature of these costs should be noted. In the U.S.A. they only consider protecting developed areas as they were in 1986. The cost estimate for Bangladesh only provides protection against a 1 in 20 year flood. Most studies excluded the costs of improved drainage and water management.

Lastly, while reviewing the studies for this paper, including a number of incomplete studies not suitable for aggregation, one concern emerged repeatedly. There is a widespread feeling that other coastal impacts of climate change could be equally or more serious than sea level rise in many countries. In particular, there is much concern about the role of changing storm frequency and intensity. The Common Methodology already address these concerns in its objectives. Therefore, investigation of other coastal implications of climate changes *and their interaction* with sea level rise should be actively encouraged within the context of the Common Methodology.

4.3 VULNERABILITY ASSESSMENT

A classification of the vulnerability of a country or local area to a 1 m sea level rise is adopted as presented in Table 5. This follows the approach in the Common Methodology. Using these vulnerability classes and Tables 4 and 5, a vulnerability profile can be developed for each country case study. These profiles are presented in Table 6. Not all the elements required for a complete vulnerability profile are available. Therefore, for some elements, an assessment has been made on the basis of expert judgement, after studying the case study report. The reports often give semi-quantitative indications of the relevant parameter. The elements of the vulnerability profile so derived are clearly indicated in Table 6. Such use of expert judgement can be used with reasonable confidence due to the band width of the vulnerability classification (Table 5). Many of the estimated values in the vulnerability profiles are taken from the IPCC-CZMS 1992 Report. Only integer values are shown in Table 6.

Nineteen country case studies contain enough information to estimate a vulnerability profile. However, the vulnerability profiles presented in Table 6 are a *preliminary* interpretation of the available information.

Six countries have a *critical* vulnerability with respect to people affected by a one-meter rise in sea level rise, while 4 countries have a *high* vulnerability. Considering people at risk, it is estimated using expert judgement that Bangladesh is in a *critical* position, while 3 countries have a *high* vulnerability position and 9 countries have a *medium* vulnerability.

For capital value at loss, 13 of the 18 countries are in a *critical* situation. Only Venezuela has a *low* vulnerability. However, the results for Venezuela exclude losses in the vital oil and port industries, so it is a low estimate of capital value at loss.

Table 5. Vulnerability Classes

IMPACT CATEGORIES	VULNERABILITY CLASSES LOW	MEDIUM	HIGH	CRITICAL	
people affected (#people / total) * 100%		<1%	1-10%	10-50%	>50%
People at Risk (people * probability) / 1000		<10%	10-100	100-500	>500
Capital value at loss <1% (total loss / GNP) * 100%	1-3%	3-10%	>10%		
Dry land at Loss (area / total area) * 100%		<3%	3-10%	10-30%	>30%
Protection /adaptation costs (total cost / GNP) * 100%	<0.05%	0.05-0.25%		0.25-1%	>1%
Wetland at loss (area / total area) * 100%		<3%	3-10%	10-30%	>30%

Considering land at loss, 12 country case studies indicate a *low* vulnerability, while the Marshall Islands have a *critical* indication and Kiribati and Bangladesh have a *high* vulnerability. Regarding wetlands at loss, 6 countries have a *critical* vulnerability, and 10 countries have a *high* vulnerability.

Based only on actual results, in 5 out of 7 case studies it is estimated that the number of people at risk can be reduced to a *low* vulnerability by implementing appropriate protection and/or adaptation measures. However, this does not imply such measures will be implemented and factors such as their cost and suitability must also be considered. In addition, the impacts and implications of these protection measures on the economic and ecological consequences of sea level rise must be considered.

Finally, the annual costs of protection structures and adaptation measures are often significant with respect to existing GNP. Two small island countries have a *critical* vulnerability: the Marshall Islands and Nevis; while 5 countries appear to have a *high* vulnerability: Antigua, Egypt, Guyana, Senegal and Uruguay. The protection costs presented here are generally for basic measures and, therefore, it is likely that more complete studies will raise these costs and increase the number of countries in the *high* and *critical* vulnerability classes. For instance, the costs for Guyana exclude any improvements to drainage.

5. COMPARISON BETWEEN CASE STUDY RESULTS AND THE GLOBAL VULNERABILITY ASSESSMENT

5.1 METHODOLOGY

An overview of the results of the Global Vulnerability Assessment (1993) is presented in Table 7, using a regional division of the world coastal zone as defined in the IPCC CZMS 1990 report.

Both the local and country case studies already discussed and the Global Vulnerability Assessment are conducted along the lines of the Common Methodology. This does not imply, however, that the results of these two sets of studies are directly comparable. A preliminary comparison of the GVA and the country studies is reported in *Global Climate Change and the Rising Challenge of the Sea*. While the number of country case studies conducted remains limited, a second comparison between the vulnerability profiles of the country studies and GVA is made here. As already noted, such a comparison can be looked upon as a combination of a top-down (using the GVA as a starting point) and a bottom-up approach (starting from the country studies).

The objectives of this comparison are to see whether the vulnerability profiles on a global scale are in line with the vulnerability profiles resulting from the country case studies. This is a test of the reliability of the GVA. If proven, a reliable methodology and data on a global scale from the GVA can serve as a useful reference for country case studies.

Such a comparison remains preliminary, since only the results of 22 country studies are presently available and these 22 studies do not provide data for all factors. Moreover, the GVA study is less comprehensive than the country studies and only covers four groups of factors: population affected and at risk; wetlands at loss; rice production at change; and protection costs. A comparison can be made for three of these factors:

- *number of people affected (no measures);*
- *wetlands at loss (no measures);*
- *costs for protection.*

The results of the country studies and the GVA are compared for the same scenarios as the aggregation: 1 m sea level rise over the next century and no development (present population and economic status).

Table 6. Country Vulnerability Profiles
(A Mean value was used for countries with an estimated range of protection coasts)

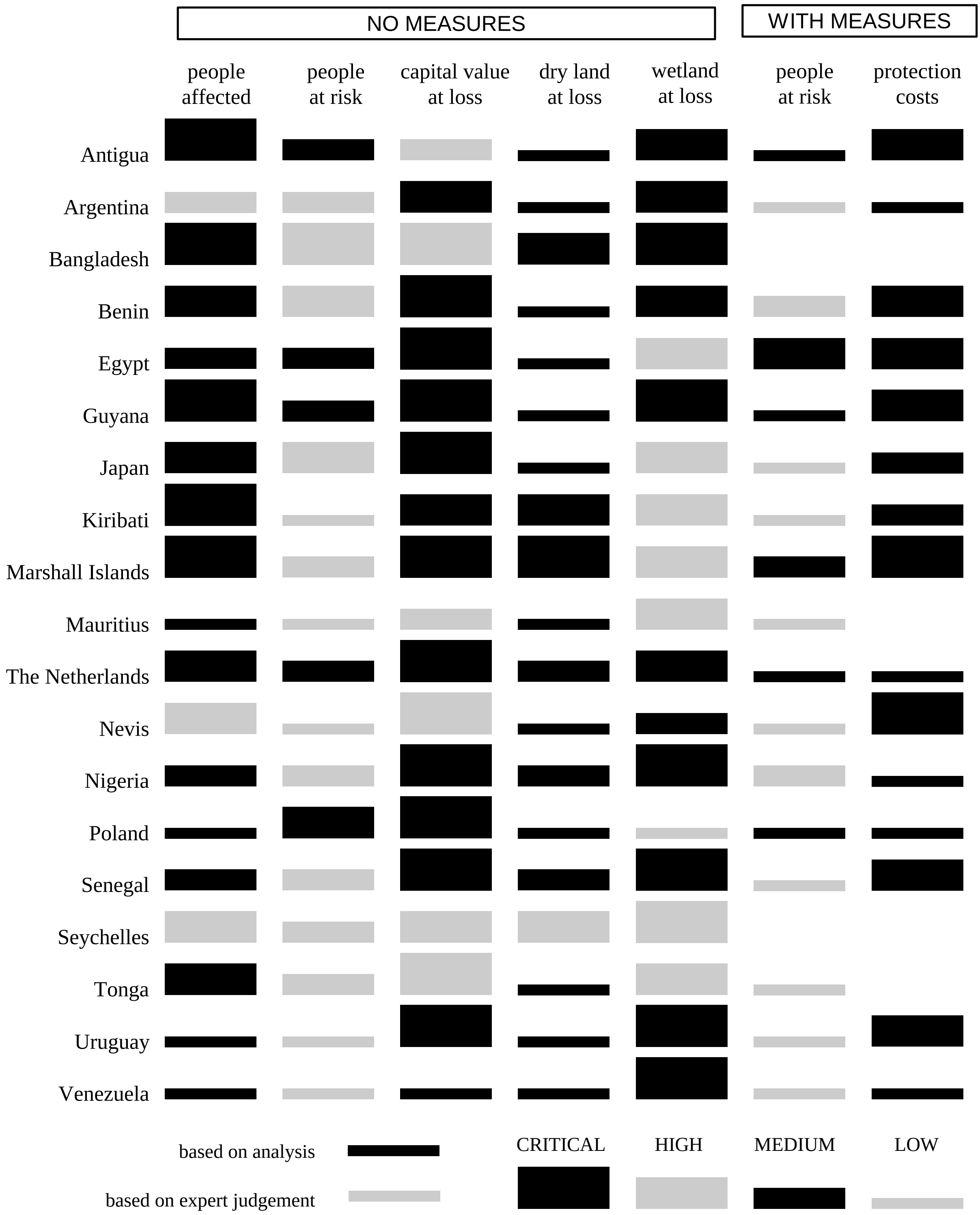


Table 7. Overview of the GVA Result, Including a Regional Analysis

	POPULATION AT RISK							WETLANDS AT LOSS				COST OF MEASURES	
	NO MEASURES					WITH MEASURES		NO MEASURES		WITH MEASURES			
	People		Popul.		increment	Popul.	Decrease		% of		% of	Total	Annual
North America	16,900	4.7%	170	0.05%	50	90	80	26,000	90%	27,100	93%	137.3	0.02%
Central America	1,160	4.1%	56	0.20%	19	6	50	3,900	53%	4,100	56%	6.7	0.23%
Caribbean islands	2,600	7.9%	110	0.33%	70	20	90	2,500	30%	3,100	38%	12.6	0.21%
S. America Atl. Coast	6,000	2.5%	410	0.17%	100	48	360	31,400	40%	36,900	47%	123.3	0.25%
S. America Pac. Coast	2,000	4.3%	100	0.22%	43	11	90	1,100	21%	1,100	21%	0.6	0.01%
Atl. Ocean small isl.	20	3.4%	0	0.03%	1	0	0	n.d.	-	n.d.	-	0.2	0.07%
North and West Europe	24,600	8.8%	130	0.05%	21	130	0	3,400	39%	4,000	45%	91.2	0.02%
Baltic states	660	1.3%	3	0.01%	1	3	0	0	-	300	60%	40.2	0.08%
N. Mediterranean	5,900	4.6%	37	0.03%	18	31	5	200	100%	200	100%	25.4	0.02%
S. Mediterranean	9,400	5.5%	2,100	1.23%	1,100	250	1,900	2,600	100%	2,600	100%	18.1	0.07%
Africa Atl. Coast	9,900	3.7%	2,000	0.75%	750	220	1,800	27,000	72%	27,200	73%	41.6	0.25%
Africa Ind. Oc. Coast	8,500	4.4%	3,600	1.87%	710	390	3,210	200	9%	400	14%	41.5	0.38%
Gulf States	540	0.6%	14	0.01%	4	3	11	n.d.	-	n.d.	-	13.8	0.05%
Asia Ind. Ocean Coast	64,100	5.5%	27,360	2.36%	6,520	3,040	24,300	14,800	35%	14,800	35%	174.7	0.52%
Indian Oc. small isl.	290	11.6%	100	4.00%	60	12	90	n.d.	-	n.d.	-	3.2	0.72%
Southeast Asia	35,500	9.0%	7,800	1.98%	2,260	880	6,900	21,200	53%	21,200	53%	66.4	0.20%
East Asia	61,700	4.6%	17,100	1.27%	2,760	2,200	14,900	6,500	71%	8,300	90%	144.6	0.06%
Pacific large islands	790	3.3%	17	0.07%	7	4	13	28,000	94%	28,200	95%	41.2	0.17%
Pacific small islands	180	7.8%	34	1.50%	20	4	31	n.d.	-	n.d.	-	4.3	0.77%
C.I.S. (former USSR)	10,210	3.5%	52	0.02%	14	52	0	n.d.	-	n.d.	-	63.1	0.02%
World	260,900	5.1%	61,300	1.20%	14,520	7,380	53,900	168,900	56%	179,600	59%	1,050	0.056%

Three problems should be noted. Firstly, possible incompatibilities may arise because several country studies are incomplete geographically while, by definition, the GVA results include the entire coastal area of each nation. For example: the results of the country studies and the GVA of several small island nations in the Pacific and Caribbean regions are not fully compatible since the country studies of Antigua, St. Kitts-Nevis, Kiribati, Tonga and the Marshall Islands only cover one single island whereas the GVA relates to all the islands of these countries. Secondly, as mentioned earlier, it should be stressed that the underlying data and the assumptions about physical and socio-economic boundary conditions and physical processes limit the accuracy of the country-by-country results in the GVA. It is therefore best to aggregate the results by region, or other means, to reduce the random inaccuracy to acceptable levels. Thirdly, for most geographic areas and factors the sample size of case studies available for comparison remains small.

The results of the comparison between the GVA and the country studies are presented in Tables 8, 9, 10 and 11. In general, the GVA results are either presented by region or aggregated by the countries which have case studies. In Tables 8, 9 and 11 only *vulnerability profiles* are shown, using integer values in all cases. The vulnerability classes (*low*, *medium*, *high* and *critical*) are the same as used in the aggregation and are defined in Table 5.

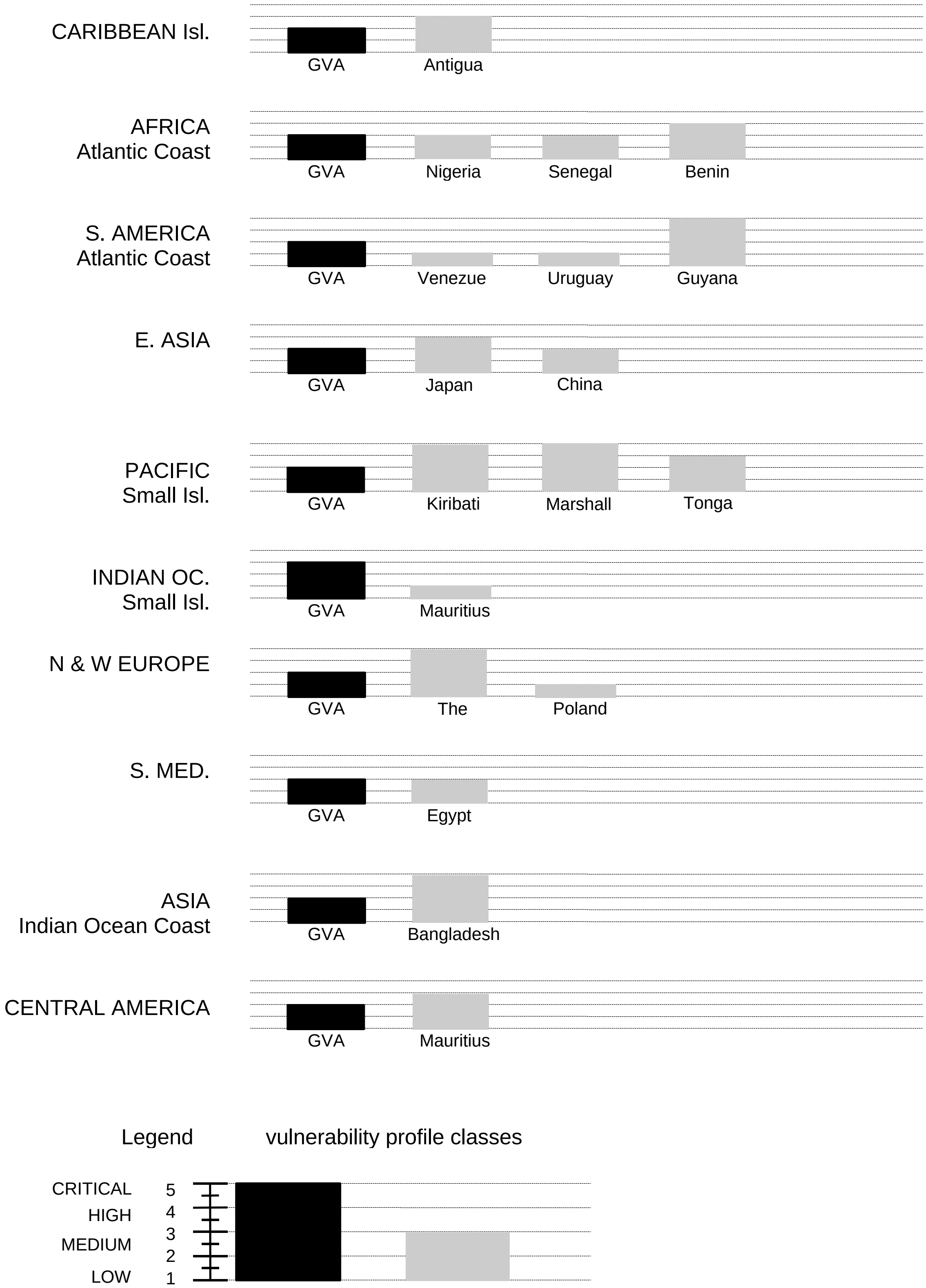
Bangladesh has a *critical* vulnerability compared to a *medium* regional vulnerability for the Asian Indian Ocean Coast. Further the absolute numbers of people affected are 22.7 million from the GVA and 71 million from the country study. This large difference reflects that the country study included change in river flow and its interaction with sea level rise. Therefore, the impact zone covers much of the country. An earlier more basic country study of Bangladesh determined the number of people displaced by land loss due to a 1-m rise in sea level. In this case the affected population was 13 million, much closer to the estimate of the GVA. This study shows that if the interaction of sea level rise with higher river flow is considered the impacts of sea level rise may be much more serious. This has important implications for the interpretation of the GVA, particularly in south, south-east and east Asia where a number of large rivers discharge into the sea across low-lying deltas.

The Egypt study agrees well with the South Mediterranean Region estimate of the GVA. The Egyptian vulnerability score is higher than the regional GVA, which is consistent with the presence of the low-lying Nile delta and associated vulnerable population.

Finally, the vulnerability profiles for the European countries Poland and the Netherlands are very different. This is due to the different geographical position of the two countries: the Netherlands is a flat, low-lying country in the large delta of several northwest European rivers, whereas Poland only has a narrow coastal zone.

In conclusion this analysis shows that the GVA appears to give reasonably good estimates of people vulnerable to flooding by storm surge. However, there are other factors such as interaction of sea level rise with river flows which may increase the number of people affected, particularly in low-lying deltas. Therefore, at the global scale, it is likely that the number of people affected by a 1 m rise in sea level may exceed the GVA estimate of 261 million (1990 population). Future revisions of the GVA should attempt to address the interaction of different causes of flooding.

Table 8. Comparison between the vulnerability profiles of the GVA and the country studies for the number of people affected



5.2.2 WETLAND AREA AT LOSS

Fourteen country case studies provide results for coastal wetlands at loss with a 1 m sea level rise. These results are presented as vulnerability profiles in Table 9 along with the GVA vulnerability profiles of the 6 regions concerned. The total area of wetland at loss for the 14 countries presented in Table 9 is approximately 62,000 km^2. In the GVA a total area of about 65,000 km^2 was calculated for these countries. Therefore, it appears that the order of magnitude of the GVA results for wetlands at loss is correct, demonstrating that coastal wetlands are highly vulnerable to accelerated sea level rise at a global scale. Further the regional comparisons show reasonable agreement.

The results for wetland loss in the country studies often lack important information, such as (1) how the wetland loss was determined; (2) is wetland migration possible; if yes, (3) how much will such migration compensate for projected losses; and (4) what is the likely direct human role in existing and future wetland losses. The country study of the U.S.A. considers wetland loss, migration and change and clearly states the assumptions that are made.

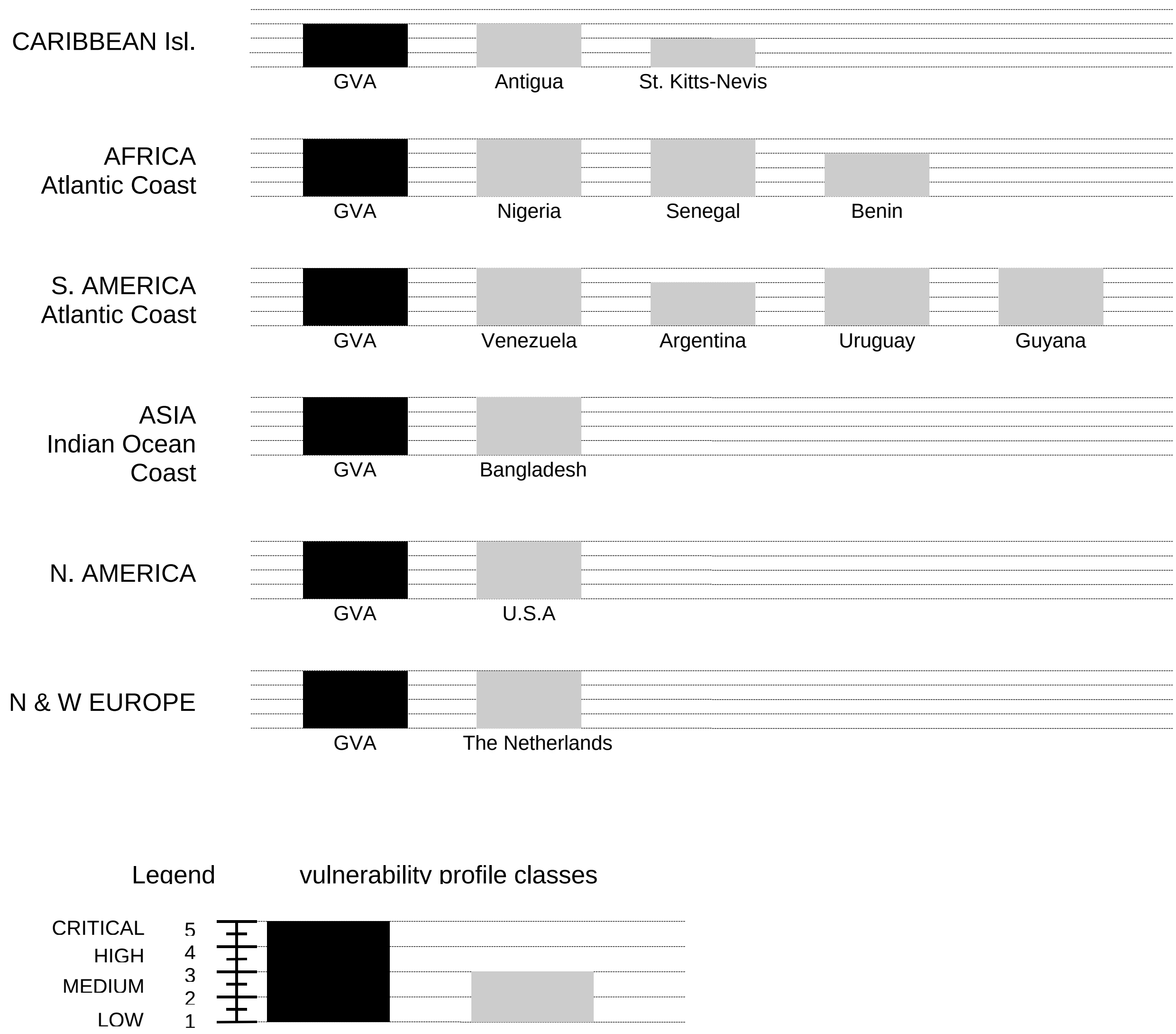
This allows investigation of the implications of protection of dry land, versus allowing upland to wetland conversion to occur. Some other studies simply treat wetlands as passive elements of the landscape that are inundated as sea level rise occurs. However, it is important to note that an ecological system can respond to sea level rise. Further, the response is non-linear: significant change (or changes) will only occur above some site-specific threshold (or thresholds). At many sites, a threshold model can be applied using experience from other sites, and hence a more useful prediction of future changes can be developed. More importantly, it establishes the correct conceptual framework to approach the problem of wetland change and loss given sea-level rise.

There is already a widespread consensus concerning the vulnerability of ecological systems to sea level rise, particularly for a one-meter rise in sea level. At the same time the accuracy and value of the present predictions within the context of the common methodology and the GVA remains uncertain. Given that we are already certain of the vulnerability of wetlands to sea level rise, future vulnerability analyses could more usefully focus on better and more detailed predictions of wetland change, including the response to a range of realistic sea level rise scenarios from present trends to one meter. If possible, the application of simple landscape models should be considered. This will provide information that is more readily integrated into coastal zone management planning. Within the context of the Common Methodology, it might be useful to develop supporting materials demonstrating different approaches to handling wetland loss and change, including wetland migration. They would be designed to guide the user rather than follow a `cook-book' approach. Similar guidance may be useful in other parts of the Common Methodology.

5.2.3 COSTS OF PROTECTION

The GVA has produced two estimates of protection costs. In Appendix D of the 1990 IPCC-CZMS Report, the costs of basic protection were given on a country-by-country basis. The estimate was based on maintaining the status quo, except in areas of very low population density. More recently, these costs have been updated to reflect the hydraulic regime of each country. This raises the costs in areas already prone to flooding and is clearly more realistic as the distinction between flooding due to sea level rise and other causes is of no practical interest to the people being flooded. The 1993 revision of the GVA approximately doubles global estimates of protection costs. However, this varies significantly from country to country with a fourfold increase in Argentina and barely no increase in Japan (5% inflation was also included to bring the estimates to 1990 values).

Table 9. Comparison between the vulnerability profiles of the GVA and the country studies for coastal wetlands at loss



The results in Table 10 are not all comparable with each other. The results for Japan, the Netherlands, Egypt and the U.S.A. reflect a more comprehensive analysis (and hence more expensive estimates) of adaptation costs. The other studies refer to more basic assessments of response costs, although the level of response which is considered varies from study to study. The studies of Argentina, Nigeria, Senegal, Uruguay and Venezuela follow the same assumptions as the 1990 GVA study.

The total protection costs, as calculated from the 16 country case studies, exceed US $378 billion. If Egypt, Japan, the Netherlands and the U.S.A. are excluded, the total for the remaining 12 countries is in the range US $11 to $17 billion. For the GVA (1990) a total of US $20 billion was calculated as protection costs for those 12 countries. On the basis of this comparison it can be concluded that the world-wide estimates of the GVA (1990) are reasonable estimates of basic protection costs. For the GVA (1993) a total cost of US $56 billion was calculated for these 12 countries. The conceptual basis for the GVA (1993) estimate is a significant improvement compared to the GVA (1990), but the existing results are insufficient to test this estimate. Future vulnerability assessments using the Common Methodology should be encouraged to adopt the conceptual basis of GVA (1993) as they will provide more realistic cost estimates. This will also provide country case studies for comparison with the GVA (1993) results.

Table 10. Comparison between Protection Costs from the GVA and the Country Studies

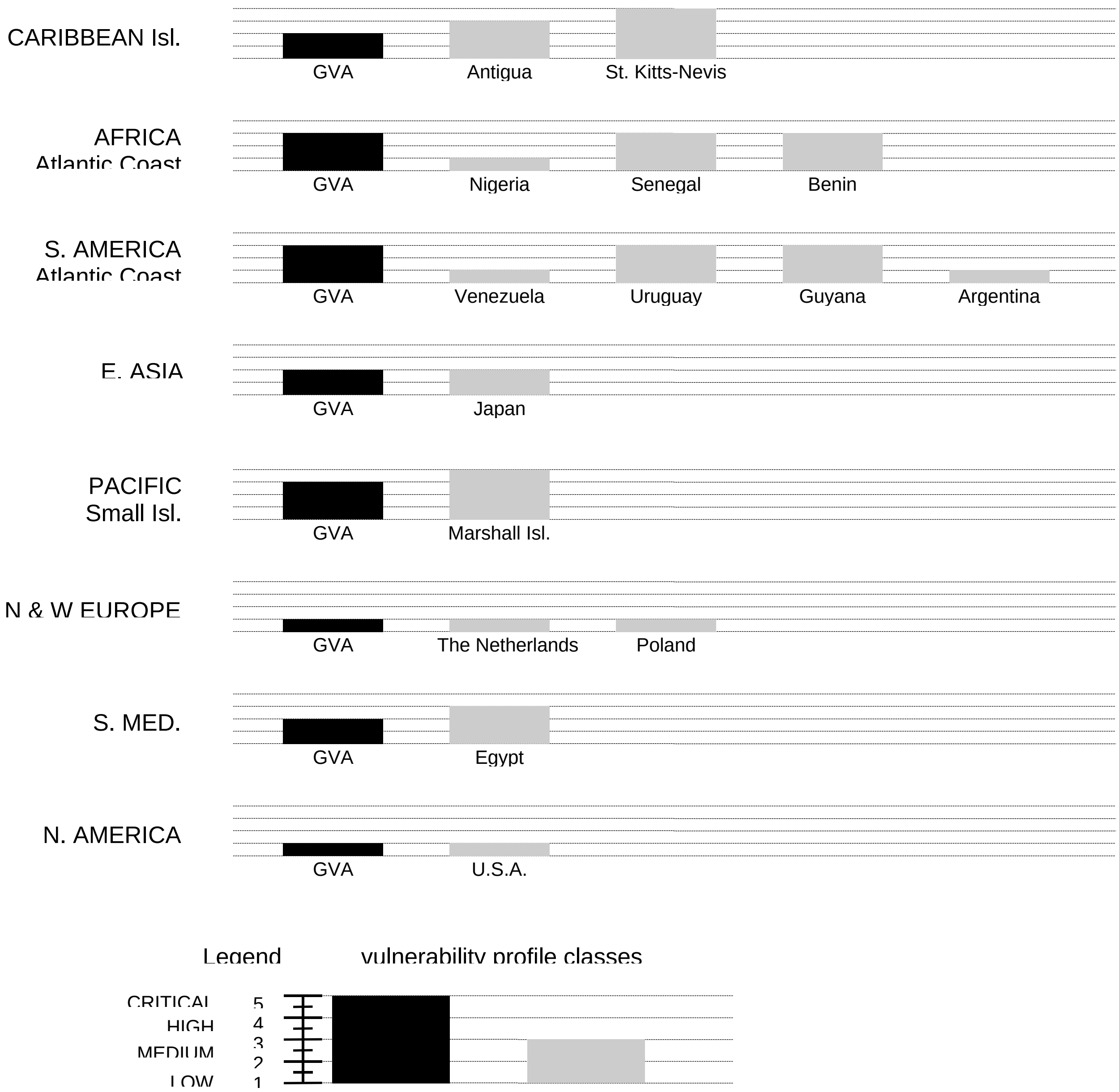
Country	PROTECTION COSTS (millions of US dollars)		
	GVA (1990)	GVA (1993)	Country Studies
Antigua	152	176	76
Argentina	3,970	15,846	1,800/3,300
Bangladesh	1,200	5,910	1,000
Benin	785	925	>430
Guyana	995	3,596	>200
Marshall Is.	322	386	380
Nigeria	3,162	6,470	1,400/1,800
Poland	3,133	6,813	1,500
St. Kitts-Nevis	140	173	53
Senegal	1,596	3,623	1,000/2,200
Uruguay	1,805	5,629	1,000/3,800
Venezuela	3,155	6,429	1,700/2,600
SUB-TOTAL	20,415	55,976	10,539/17,339
Egypt	3,085	4,673	13,133
Japan	22,378	23,688	>200,000
Netherlands	4,211	8,995	12,286
U.S.A.	86,819	97,391	>143,000
TOTAL	136,908	190,723	>378,958

Protect/adaptation costs are significantly above the GVA (1993) estimates if more realistic environmental and decision-making processes are considered (e.g. country studies of Egypt, Japan, the Netherlands and the U.S.A.). Even these results are not complete. The results for Japan are incomplete, while the results from the U.S.A. only consider protecting developed areas as in 1986. Moreover, the Egyptian case study considers the costs for adaptation of water management and found that there appear to be limits to such adaptation controlled by the availability of freshwater. This indicates that the GVA (1993) protection costs only serve as a lower limit for the global costs of protection/adaptation towards a one-meter rise in sea level.

Bearing in mind the limitations just discussed, Table 11 shows vulnerability profiles of the GVA and country studies for protection costs. A general pattern of lower vulnerability in North and West Europe and East Asia, and higher vulnerability elsewhere is supported. Interpretation beyond this level is probably not meaningful. The *critical* vulnerability of St Kitts-Nevis and the Marshall Islands is noteworthy, particularly considering that the case studies were not true national studies. It reinforces the conclusion that many island states are highly vulnerable to accelerated sea level rise. The *high* vulnerability of Antigua, Benin, Egypt, Guyana, Senegal and Uruguay should also be noted, reflecting the importance of the coastal zone in these countries and/or the present (small) size of the economy.

Lastly, the response option chosen in the GVA - "protection of all areas with a population of more than 10 persons/km^2" was questioned in some studies. Based on existing land use, areas of low value were often protected under this option. Therefore, it sometimes seemed an implausible response scenario. The studies of Argentina, Nigeria, Senegal, Uruguay and Venezuela evaluated an intermediate option "important areas protection". This is defined as protection of all medium to highly developed areas, as well as strategic areas. (The country study of the U.S.A. was based on similar assumptions, although a different methodology). These case studies used oblique aerial videography to develop a classification of existing coastal land use and, in turn, selected areas to be protected. It is recommended that future revisions of the GVA consider evaluating a second protection option, set at a higher population density threshold. Selection of an appropriate global threshold will require more consideration of the country studies.

Table 11. Comparison of the vulnerability profiles of the GVA and the country studies for costs of protection. (For countries with an estimated range of protection costs, a mean value was used).



6. CONCLUSIONS

Aggregation of country case studies

To date, 22 country case studies and 8 local area case studies have produced quantitative data related to the vulnerability of the country or an area to an accelerated sea level rise. For 19 countries vulnerability profiles are presented. They display 7 different aspects of the relative vulnerability of each country to sea level rise It appeared that 6 countries, including 3 small islands states, have a *critical* vulnerability with respect to the number of people affected by sea level rise. With measures, it appears that the vulnerability with respect to the number of people at risk can be reduced to *low* for 5 out of 7 of the case study countries, where this is reported. Such a conclusion does not demonstrate that such a response is within the economic capability of these countries, or that such a response will be chosen.

As for the capital value at loss, 13 out of 18 countries have a *critical* vulnerability, and only one country has a *low* vulnerability. This *low* classification could be an underestimate. Regarding the costs of protection measures, 2 small island states have a *critical* vulnerability, while another 6 countries have a *high* vulnerability.

For land loss, 15 out of the 18 countries have a *low* or *medium* vulnerability. For two small islands the vulnerability to land loss is *high* or *critical*. Bangladesh, a largely deltaic country has a *high* vulnerability. As for the vulnerability to coastal wetlands at loss, 16 out of the 18 countries have a *high* or *critical* vulnerability.

Comparison between country case studies and the GVA

It appears that the order of magnitude of the GVA results is correct for the number of people affected by sea level rise, the basic costs for protection (GVA 1990) and the area of coastal wetlands at loss. The GVA (1993) protection costs cannot be tested at present, but they appear to serve as a useful lower bound for the costs of comprehensive protection/adaptation to a one-meter rise in sea level.

This comparison also suggests some possible improvements to both future case studies and revisions of the GVA. The GVA(1993) method for calculating protection costs includes the hydraulic regime (effectively existing flooding problems) and this approach should be encouraged within the Common Methodology to develop more realistic results. The population criteria used to select protection within the GVA appears to small based on some of the country studies. This would give protection costs that are unreasonably high. Consideration should be given to developing and applying a second higher population threshold in future estimates of protection costs within the GVA. Lastly, the interaction of sea level rise with river flooding should also be considered, particularly in the low-lying densely-populated coastal areas of Asia. Based on the country study of Bangladesh, this could significantly increase the number of people affected by sea level rise in a number of countries.

The Common Methodology

Increasing experience is being gained with the Common Methodology and it is contributing to a better perspective of national, regional and global vulnerability to sea level rise. At the same time, the local and country studies are often not easily comparable. The Common Methodology deliberately avoided using precise definitions and prescription of methods to allow maximum flexibility to the user. At the Tsukuba Workshop, there was a call for a Common Framework rather than a Common Methodology to reflect the diversity of conditions around the globe. In practice, this review shows that this is already the case and all the studies differ to a lesser or greater extent. At the same time, use of common definitions and a clear description of the methods and assumptions employed allows the results to be utilized in regional and global analyses. This maximizes the benefits of each study and justifies continued use of a Common Methodology (or Framework).

The aggregation and comparison of the wetland losses was one of the more difficult areas to assess. However, there are already sufficient results to demonstrate that coastal wetlands are highly vulnerable to sea level rise at a global scale. Future studies should concentrate on improving our understanding of this vulnerability and obtaining information that will more directly help in the management of these systems. The application of non-linear approaches to wetland response to sea level rise should be encouraged as it will establish the correct conceptual framework for such studies. This is an important step towards integrated coastal zone management. This could be supported by guidelines developed specifically for user's of the Common Methodology.

Lastly, aggregating the studies show repeated interest in the other coastal effects of climate change, such as increased storminess. Efforts to look at vulnerability to these other factors are already a part of the Common Methodology and should be encouraged.

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APPENDIX 1. CASE STUDIES - SUMMARIES

1. INTRODUCTION

At the Margarita Island Workshop in 1992, 25 case studies carried out since 1990 were presented and analyzed in the report *Global Climate Change and the Rising Challenge of the Sea*, including a comparison with the first version of the Global Vulnerability Analysis (GVA). This work extends this earlier review to reflect the available information in November 1993. The case studies presented at Margarita are included here, although half have been updated: Argentina, Australia, Bangladesh, China, Egypt, Guyana, Japan, Nigeria, Senegal, Uruguay, U.S.A. and Venezuela the results reflect updated and improved results. A total of 36 countries are presented here. In reviewing the following summaries of the case studies, the reader should bear in mind the following points:

° Case studies in at least 11 countries were begun before the common methodology was developed. This fact, in conjunction with the lack of appropriate data, precluded the universal application of the methodology. In addition, some of the results are preliminary presentations of ongoing studies.

° Most of the summaries reflect impacts for a one-meter rise in sea level. This is at the upper end of the sea level rise predicted by the IPCC 1990 Scientific Assessment for the year 2100. The subsequent IPCC 1992 Update reduces emission scenarios which implies a high scenario of about 0.9 m in the year 2100. Therefore, a one-meter rise still provides a useful upper bound to vulnerability to sea level rise.

° The capital value of infrastructure was based on estimates of the current infrastructure in place. Actual values could be higher or lower, since neither depreciation nor growth of these assets was considered over time in most of the case studies.

° For most studies, changes in population or other socio-economic factors over the next century were not considered.

° In most cases, only capital costs of controls or adaptation measures were estimated. These costs, which would be borne over the next century, were based on current costs and were not discounted to present value. In most cases, operation and maintenance costs of measures were not included.

° Where possible, cumulative cost measures were compared with the current annual gross domestic product of the area being studied. This gives a relative measure of these costs, based on existing economic conditions.

The results of the studies are aggregated into the three following geomorphic categories: (1) small islands, (2) deltas, and (3) continental and large island shorelines. While there are overlaps among these categories, this grouping is useful for extracting common issues shared by nations and strategies for dealing with those issues.

3.1 SMALL ISLANDS

Many small island nations are very vulnerable to sea level rise. Those with atolls are particularly vulnerable, since they are generally very small, lie within three meters of current sea level, and have no land at a higher elevation where populations and economic activities could be relocated. Although other types of islands have areas well above sea level, their populations and economic activities are often concentrated along low-lying coastal plains.

The coral reefs, sandy beaches, mangrove forests, and hard rock cliffs that make up island ecosystems are very important for fisheries, beach protection, agriculture, and tourism. Water pollution, dredging, sand and coral mining, uncontrolled coastal construction, inadequate land use planning, and other nonclimate factors are all increasing the vulnerability of small island nations to sea level rise. Other common characteristics of small islands include small natural resource and economic bases, underdeveloped human resources, and some of the highest rates of population growth in the world.

An accelerated rise in sea level would further threaten human and natural resources with inundation, coastal erosion, increased flooding, and loss of fresh water and arable land. The implications of other climate change factors such as changing storminess or precipitation, have not been evaluated, but could be equally or even more serious in some cases.

The retreat option is not feasible for many small island nations. Moreover, the accommodation - and even the protection response strategies could result in major lifestyle changes, threatening a nation's cultural identity (e.g., housing, land tenure systems) and economic growth potential.

The following studies indicate that the responses to sea level rise could often represent a significant additional burden that may require international assistance. Such assistance could include scientific studies and monitoring, data and information exchange, national capacity building through training and appropriate technology transfer, development and implementation of integrated coastal zone management plans, including mitigation of climate change.

Antigua

The majority of the population of the nation of Antigua and Barbuda is concentrated on Antigua. The island's 193 km of shoreline includes 21 km of mangroves and 41 km of sandy beaches developed for tourists. If no additional protective structures are built, a one-meter rise in sea level would inundate or erode approximately 26 km^2 of land, or approximately 2 percent of Antigua's land mass.

Only 25 percent of Antigua's lowland coast is developed. Protecting these areas would require 7.5 km of sea walls, 4.5 km of breakwaters, and 8 km of beach nourishment. The total capital cost would be about $200 million. On an annual basis, this cost would be about 1 percent of the nation's gross domestic product. Because 75 percent of the coast is undeveloped, planned retreat response options, such as setbacks and other planning tools are feasible response options to avoid increasing vulnerability to sea level rise.

Australia - Cocos (Keeling) Islands
These are an isolated group of coral atoll islands in the Indian Ocean, with a total land area of only 14 km^2. In 1991, the population was 647 persons. Economically, the islands are dependent on mainland Australia. They have a number of contemporary environmental problems including some deterioration in ground-water supply and some coastal erosion.
The uncertain interplay between destructive and constructive (reef-growth and reworking) processes under sea-level rise makes a forecast of impacts difficult. Erosion and inundation are possible with consequent reduction in ground-water availability. In terms of possible responses, planned retreat and total protection are not feasible given the small size of the islands and their long (128 km) perimeter. A combination of soft engineering responses with appropriate planning and land management are advocated. As a last resort, evacuation of the island residents to mainland Australia could be considered.

Kiribati - Tarawa
The Republic of Kiribati is made up of 33 low-lying coral reef islands in the central Pacific. The country's economic base is extremely narrow, depending on copra production, fish exports, and substantial foreign assistance.
There is great uncertainty about the effects of sea level rise on Kiribati's islands due to lack of baseline data. Scientific predictions run the gamut from erosion, to redistribution, to accretion. Fully protecting all the islands against sea level rise is not feasible, and totally protecting the two highly populated islands of Betio and Buota could only be undertaken with foreign assistance. Shoreline vulnerability analysis is needed to determine where building setbacks should be required and to identify which beaches and mangrove areas should be protected.

Moorea
Moorea is a 70 km long mountainous and coralline French Polynesian island. Its limited dry, flat land area is mostly dedicated to residential (2,400 homes) and other buildings. The principal economic activities include agriculture and tourism.
Moorea experiences significant floods and erosion during cyclones, which strike about four times per decade. Tourism, which brings in an estimated $41.5 million a year in revenue, is the economic activity most threatened by a one-meter rise in sea level. (Moorea's gross national product is $136 million.).
Partial protection of Moorea is the recommended strategy against a one-meter rise in sea level. This would involve protecting the island's agricultural lands and tourist resources.

Nevis
Nevis is the smaller island in the nation of St. Kitts - Nevis. Its 40 km coastline consists of 10 km of sandy beaches, which attract thousands of tourists annually. Urban areas are also located along the coast, and much of the island's beaches are being mined for construction, which is accelerating coastal erosion in certain areas to as much as four meters a year.
A one-meter rise in sea level would inundate or erode 3 to 4 percent of this island, threatening coconut plantations and tourist resorts. Protecting existing development would require 2.5 km of seawalls, 3.0 km of breakwaters, and 6.5 km of beach nourishment, for a total cost of $140 million. On an annual basis, this cost represents 6 percent of the island's GDP. Because only about 25 percent of the existing lowland coast is developed, retreat in the form of set backs may be cost effective for future development.

Republic of the Maldives
The total area of the Maldives is about 90,000 km^2, but only 2 percent of that area is land. Most of the islands are coral reefs that are no higher than 1 or 2 meters above mean sea level (MSL). The main airport, which is critical to the tourism industry, lies 1.5 meters above MSL.
The reefs are important not only for protection but for the fishing industry and native subsistence. Consequently, all of the Maldives are extremely vulnerable to future sea level rise if the coral growth (which replenishes the sand supply) cannot keep pace with the rate of sea level rise and if coral and sand mining are not managed properly. Even more important would be any changes in weather patterns, where winds and storm surges would place the entire population at risk.
Retreat and protection are the two most commonly considered response options for the Maldives. Current storms have already caused the Maldives to build protective structures (breakwaters and seawalls) at great expense (e.g., shore protection costs $800/meter). Protecting 10 km of shoreline for Male alone would cost nearly $8 million, with a total cost of protection for the Maldives estimated at nearly $1 billion. The Maldives has already evacuated residents on four of the low-lying islands to larger islands because the financial resources are not available to develop and protect all the islands. These issues spurred the nation to formally initiate coastal zone management through legislation, planning, and monitoring.

Republic of the Marshall Islands
Situated in the western Pacific, the Republic of the Marshall Islands is comprised of 29 atolls and 5 islands, with an average elevation of less than 2.4 meters. The Republic has a narrow resource base, underdeveloped human resources, serious problems of water supply, and very high rates of population growth.
A study of Majuro atoll, where the capital is located, has found that protection against a 0.3 meter rise in sea level would cost 1.5 to 3.0 times the present GDP. A dilemma confronting this nation, like most atolls, is determining the source of the necessary materials for raising land surfaces. While less material would be required, the feasibility of dikes is unclear, due to the permeable soils and potential loss of ground water. Whether suitable protection materials are available is also unclear. Even if they are available, protection would still result in major lifestyle changes, potentially threatening the nation's cultural identity, social patterns, and economic growth.

Seychelles
The Seychelles archipelago occupies an area of 1.3 million km^2 in the Indian Ocean, but has a total land area of only 447 km^2, comprising 115 islands. The bigger (high) islands such as Mahe (5 by 27 km) have a granite core, but many of the islands are low-lying coral atolls.
The interior of the granite islands is often unsuitable for settlement, which is concentrated near the shore. The 1993 population was about 71,000. An international tourist industry has developed since the opening of the Airport in 1976.
In addition to sea level rise, the possibility of an increase in storminess and cyclone activity is of great concern to the Seychelles. A vulnerability analysis of the Seychelles is required, including this factor. Awareness of the threat of sea level rise is high and it is already considered in some planning decisions - new reclamations for coastal roads are designed for a one-meter rise in sea level.

Kingdom of Tonga - Tongatapu Island
This nation consists of about 170 islands, 36 of which are permanently inhabited. The case study focused on Tongatapu Island, whose 67,000 people account for two thirds of the nation's population.
A one-meter rise in sea level would inundate 7.2 km^2 - this is only 3 percent of the island's area, but is home to 10 percent of its population. The 1982 tropical cyclone Isaac flooded 23 km^2, including residential areas accounting for one third of the island's population. With a one-meter rise in sea level, such a cyclone would flood 37 km^2 and the residences of 45 percent of the island's population.
Totally protecting Tongatapu Island from rising sea level would be economically infeasible. The most likely strategy would be a mixture of retreat, accommodation, and protection, with land-use planning for new development, preservation of the coast's natural protective functions, and storm surge protection for the most densely developed areas. External financial and technical assistance would be necessary to carry out such a strategy.

3.2 DELTAS

Many deltas are densely populated and are experiencing rapid population and economic growth. At the same time all deltas naturally subside and most already experience rates of relative sea level rise in excess of the global rise in sea level. Natural flooding and the resulting sedimentation may enable deltas to keep pace with existing or even higher rates of sea level rise. However, residents naturally desire flood protection and such flooding is often prevented. Changes within the catchment such as rainfall or land cover may also influence the delta. Importantly, the construction of upstream dams reduces sedimentation in deltas, accelerating erosion and subsidence. These problems can be seen today in the Nile, Niger, Mississippi, and other deltas. These and other human activities, such as hydrocarbon and groundwater extraction, uncontrolled land reclamation, large-scale dredging, and inadequate land-use planning, increase the vulnerability of deltas to an acceleration in sea level rise.
Many low-lying deltaic plains already suffer the effects of flooding and storms. In low-lying deltaic areas, a one-meter rise in sea level would increase the risk of floods, cause shorelines to retreat tens of kilometers, and could deprive tens of millions of people of their current means of subsistence.
Many coastal wetlands are located in highly populated and developed deltaic areas. The use of structural measures to protect populations can limit the ability of these coastal wetlands to migrate inland. Consideration of sediment transport and budgets within coastal management planing can be a significant factor in reducing vulnerability to accelerated sea level rise. Therefore, integrated coastal zone management in deltaic settings must consider the upstream catchment.

Bangladesh
Bangladesh is already one of the most densely populated countries of the world: over 110 million people live in an area of 144,000 km^2. Practically the entire country lies on the delta and floodplain of the three major rivers of the Ganges, Brahmaputra and the Meghna and hence will be influenced by sea level rise. The country is already vulnerable to a number of natural and manmade hazards, most particularly flooding both from the rivers and the surges in the Bay of Bengal. Therefore, the coastal zone will be particularly vulnerable to climate change and sea level rise, particularly if they increase the intensity or frequency of these natural hazards. Population growth and increasing demand for water also need to be considered.
Ten scenarios of future change were investigated to better understand the implications of climate change and sea level rise. Based on existing population, 24 million people are presently vulnerable to flooding. Given a one-meter rise in sea level and a 15% increase in precipitation this increases to 71 million people. It is estimated that at least 13 million of these people would be displaced from their homes, assuming no response. Agricultural production could be depressed significantly by a combination of land loss, salinization, decreased freshwater availability and higher temperatures. The importance of understanding the interaction of different aspects of climate change and human actions is well demonstrated in Bangladesh.
There is a need for both national, regional and international action. This includes development of national capacity and coastal zone management. Retreat is not a practical solution in Bangladesh, because of the country's high and growing population density. Where people do migrate, they tend to move to areas as vulnerable as the ones they left, such as newly accreted coastal lands, or they emigrate to India. To implement appropriate responses, Bangladesh would need substantial external financial and technical assistance. At the regional level, the worst impacts of climate change and sea level rise are associated with greatly reduced freshwater flows in the dry season. Therefore, it is particularly important to establish an equitable sharing of freshwater flows with Bangladesh's neighbors.

China

China’s long, densely populated coastline is rapidly developing and rich in resources, particularly on the Chang (Yangtze), Huang (Yellow), Zhu (Pearl), and Liao river plains and deltas. The gross output of industrial and agricultural activities within the coastal zone and deltas is about one-fourth of China’s GDP. The overexploitation of ground water in such industrialized and economically important cities as Shanghai and Tianjin has accelerated subsidence in the low-lying coastal plains, and hence the rate of relative sea level rise. Locally, the ground surface near Tianjin is falling at 5 cm/yr. This has exacerbated existing problems of saltwater intrusion and flooding, as well as reducing the height of coastal dikes and the protection that they afford. In addition to sea level rise, China's already severe storms may become more frequent and more intense.

While estimates vary, a one-meter rise in sea level may threaten an area as large as 125,000 km^2 with inundation and/or increased flooding. The existing population of this area is huge, being 72 million people, while many billions of dollars of industrial and agricultural resources and infrastructure will be at risk. In the North China coastal plain, a one-meter relative rise in sea level could occur in several decades, rather than the century or more expected due to global changes. Protection of the huge populations of Shanghai and Tianjin (respectively, 13 and 7 million people) alone would also cost several hundred million dollars.

Protection is already being upgraded to stop existing flooding problems around many developed areas such as Shanghai. Among the responses to sea level rise being considered in China are upgrading or building seawalls around developed areas, establishing setback codes for future development, retreating from sparsely populated areas frequented by severe storms, and managing ground-water exploitation to avoid anthropogenic subsidence. In Shanghai the problem of subsidence has been brought under control, but large and immediate subsidence problems remain around Tianjin.

Egypt

Egypt has 3,500 km of coast - 1,550 km on the Mediterranean, including sheltered lagoons, 1,500 km on the Red Sea and 450 km in and around the Suez Canal. The lower Nile delta is already known to be highly vulnerable to sea level rise. Egypt’s vulnerability could increase as existing economic activities (agriculture, tourism, trade) currently show a movement to the coastal areas. Managing this growth for long-term benefit presents Egypt with significant challenges.

The lower Nile delta has moved from a slightly accreting trend, to a strongly eroding trend since the Aswan High Dam effectively turned off the supply of sediment to the delta. A one-meter rise in sea level could displace 4.7 million people from their homes. If likely population growth to 2020 is considered, the number of people displaced increases to 8.5 million. Capital values of $59 billion could be lost.

Protection of the resident population and capital values would cost about $13 billion (or 45 percent of Egypt’s current GNP). Such protection would require a national response strategy. This protection would not stop ecological damage in the coastal lagoons and marshes, and would only limit saltwater intrusion impacts on agriculture. It is recommended that coastal zone management in the delta should consider both short-term problems and long-term problems such as sea-level rise.

Guyana

The population and economy of Guyana are mainly located along the coast. About 90 percent of the country’s population lives in the coastal zone, which produces 25 percent of the GNP ($330 million) through agriculture and 30 percent through industrial activities. The populated coastal zone consists largely of polders which are reclaimed swamps with an elevation below high tide. Of the 430 km coastline, rigid sea defense protect 360 km of Guyana’s coastline, providing a strong testimony to the country’s vulnerability to sea level rise. Any increase in sea level compromises the protection offered by these defenses and the existing gravity-based drainage. A one-meter rise in sea level would directly affect about 600,000 (or 80 percent) of Guyana’s population. Assuming no response, about 1,900 km^2 of productive, mainly agricultural land, would be inundated destroying most of the national agriculture and industry.

Traditionally, retreat has been the response to shore recession in Guyana, but this is increasingly less practical as use of the coastal zone increases. A preliminary estimate finds the costs of protecting Guyana's coastline to be about $200 million, excluding costs to improve drainage. These costs include fortifying 110 km of existing seawalls, building 125 km of new seawalls, and raising 125 km of earth dams. An institutional framework to address the problems of the coastal zone is lacking in Guyana. This is mainly because a number of government agencies have interests in different aspects of the coastal zone, with no central coordination. Internationally, cooperation between Guyana, Surinam and French Guyana is suggested because of their common problems in the face of sea level rise.

India-Orissa and West Bengal

The coastal areas of Orissa and West Bengal consist of two large deltas-the Mahanadi and the Ganges. They are bordered by the world's largest mangrove forest (the Sunderbans), and the Chilka Lagoon, which is an important sanctuary for migratory birds and a fish farming center.

Under the retreat scenario, a one-meter rise in sea level would inundate about 1,700 km^2, of which 1,500 km^2 is highly productive agricultural land. In addition, over 700,000 people would be displaced, and valuable educational and medical infrastructure would be lost. Under a protection strategy, it would be necessary to upgrade existing structures and build an additional 4,000 km of new dikes and seawalls.

The Netherlands

As a low-lying deltaic country, the Netherlands has protected itself for centuries against human-induced subsidence and rising sea level by building and improving its coastal structure (e.g., dams, dikes) and natural defenses (e.g., dunes, barriers) and by adapting its agriculture to more saline conditions. The country is densely populated (average 450 inhabitants/km^2) and has productive and highly valuable economic areas lying below mean sea level.

About 65 percent of the GNP is earned in the low-lying coastal zone. Therefore, the only management option in the event of a one-meter rise in sea level during the next century would be to strengthen the country's existing protective structures, to maintain existing safety standards, and to take adaptive water management measures, such as increasing the drainage pumping capacity. The socioeconomic effects of these actions would be minor. The annual costs would be less than 0.1 percent of the country's annual GNP. However, present estimates reveal that more than a third of the country's coastal wetlands (which have been designated as areas of international importance) would be degraded because they cannot migrate inland or adapt because of expected sediment shortages. This will have serious consequences for coastal fisheries and other natural resources.

Nigeria

Much of Nigeria's population and economic activity is located along the country's 853 km of low-lying coastline, including the vital oil industry in the Niger delta and the former capital city Lagos. The coastal zone, defined as the land seaward of the 2-meter contour, is up to 150 km wide in the Niger delta. A one-meter rise in sea level could erode and inundate 18,000 km^2 of land, forcing about 3.2 million people to relocate their homes, and damaging assets valued currently at $18 billion. Over $10 billion of these assets are related to the oil industry.

Protecting the country's entire coastline appears infeasible, particularly the Niger delta with its extensive mangrove swamps and other wetlands. The highly developed coastal areas and oil infrastructure alone would cost $550-700 million. Protection of all moderately developed areas and planned evacuation of unprotected areas would cost at least $1.4 to $1.8 billion. If this investment occurred over 50 years (2051 to 2100), it would represent an annual cost of over 0.5 percent of the national gross investment in 1990. Over 700,000 people in the less developed Niger delta and the Mahin Mud Coast would require relocation to safe locations, and 17,000 km^2 of predominantly wetlands would be lost. The reaction of these people to such a relocation is unknown. Further studies of vulnerability and possible responses to sea level rise are recommended.

Vietnam

Vietnam is vulnerable to accelerated sea-level rise, particularly in the Red River Delta in the north and the Mekong River in the south. The Red River Delta covers 15,860 km^2, of which 9,000 km^2 is arable land which produces 22 percent of the national rice crop, and other important staple and cash crops. It is densely populated with 16 million inhabitants, including the capital city - Hanoi. Over 7,000 km^2 is below 3 m, while nearly 3,000 km^2 is below 1 m. Levees have been built along the river to control flooding since at least the 13th Century. An extensive system of levees exists and the system of coastal dikes is being upgraded to protect against typhoon-induced flooding. The total area of the Mekong delta within Vietnam is about 39,000 km^2 of which about 24,000 km^2 is cultivated. Much of the remainder is mangrove forest.

Sea level rise threatens about 20,000 km^2 of land, mainly situated in the deltas and will compromise the existing system of dikes and levees in the Red River delta. The cities of Haiphong, Danang and Vungtau are also threatened. Other impacts of climate and regional change such as changing patterns of run-off and deforestation are also of concern. The only possible response is to upgrade the dikes and levees to maintain existing levels of protection. Pumping is already used to control water levels in many areas and this will increase if sea level rises.

Studies of the implications of climate change on the delta, including sea level rise continue.

3.3 CONTINENTS AND LARGE ISLANDS

The coastal zones of continental states and large island nations contain a diversity of biogeographic environments and functional uses. Some of these environments are physically vulnerable to sea level rise (e.g., barrier islands, wetlands, estuaries), while others are not (e.g., rocky bluffs). Many coastal states with predominantly continental shoreline environments have the benefit of elevation, inland space, and stable shorelines that will provide sanctuary from a rising sea. Nevertheless, their low-lying coastal plains have often been the site of the greatest growth and development because of early settlements, transportation corridors, agriculture, etc. The long-term management of these areas present a challenge for the development of appropriate response strategies for accelerated sea level rise.

A significant portion of the world's coastal wetlands are located in low-lying coastal plains - notably estuaries and lagoons. Some of these systems appear vulnerable to existing rates of relative sea-level rise, let alone accelerated sea-level rise. Human development and rigid protective structures would limit the inland migration of these ecosystems given sea level rise. The use of dynamic and flexible responses, considered in the framework of a coastal zone management plan, would assist their continued survival. The following studies extend from local areas to entire nations.

Argentina

A one-meter rise in sea level would inundate and erode at least 3,500 km^2 of land in Argentina, including large areas of wetlands, much of the Parana delta and parts of the capital city Buenos Aires which are built on low-lying land next to the Rio del la Plata. Most of the impacts would be north of Mar del Plata, and would destroy land and structures with a value of about $5.5 billion.

Protecting the developed shoreline against a one-meter rise would cost $580 to $1,300 million, of which up to 75 percent would be devoted to beach nourishment. Assuming that this investment occurred over 50 years (2051 to 2100), it would represent an annual undiscounted cost of 0.1 to 0.3 percent of the national gross investment in 1990. A comprehensive coastal zone management strategy is recommended to reduce Argentina's vulnerability to sea level rise. Given the high concentration of vulnerability in northern Buenos Aires Province, action at a province level is also suggested.

Australia

Australia is an island continent and has one of the world's longest coastlines: 30,000 km including Tasmania; and over 70,000 km when the numerous offshore islands, estuaries and bays are added. Administratively, the coastal zone is 50 km wide and hence occupies about 1.3 million km^2 or 17% of the total land area. Geomorphologically the coast is diverse with extensive sandy shores, rocky coasts and muddy areas. About 14.3 million people, or 86% of the population, live in the coastal zone and 26 percent of the total population live within 3 km of the shore. From 1971 to 1991, the coast was the major area with population growth and this is anticipated to continue. The coast plays a central role in the culture of most Australians.

At a national level, the possible effects of climate change are poorly understood. The importance of climatic variability is already acknowledged. For instance, many Australian beaches show cyclic erosion and deposition phases in response to changing storminess. It is also clear that natural vulnerability to climate change may be increased by inappropriate coastal uses and management practices. This shows that future coastal planning should aim to avoid any unnecessary reduction of planning options for responding to climate change.

In Western Australia, coastal management is directed by plans that guide the use of coastal land for conservation, recreation, and development. Second only to Perth as a tourist mecca, Geographe Bay is among Australia's most vulnerable areas to sea level rise. A one-meter rise in sea level could erode 100 meters of Geographe Bay's sandy shoreline, reducing its appeal to tourists and people retiring to the area. Furthermore, certain buildings and aboriginal sacred sites that will be threatened have a cultural and historic importance greater than can be monetarily evaluated.

Belize

The coral cays in Belize form the largest reef in the western hemisphere. Tourism, which is largely based on the coral cays, is the largest component of the service sector and contributes about 18% to GDP. While the response of the cays to a one-meter rise in sea level is uncertain, the tourist sector is highly vulnerable. Nationally, over 1,900 km^2 of land could be inundated with a population of 70,000 (35% of the national total).

Coastal cities will require protection. Elsewhere coastal development is low and there is a great opportunity to plan future development to minimize vulnerability to climate change and sea-level rise. A plan for the tourist industry would be particularly helpful. Addressing these planning issues will require external assistance in capacity building.

Benin

While the coast of Benin in West Africa is only 125 km long, it is highly vulnerable to sea level rise. The shoreline is characterized by barrier islands backed by narrow lagoons with wetlands. It is already experiencing widespread erosion and unrestricted development, including wetland and mangrove destruction. Many of these existing problems can only be fully understood if the entire Gulf of Benin is considered, including part of Ghana, Togo, Benin and part of Nigeria.

The coastal zone is a vital element in the Benin economy. All airports and port facilities, 75 percent of industrial production ($200 million/yr) and 1.35 million people (25 percent of the national population) are located within 2 meters of present sea level. A growing international tourist industry is also located in the coastal zone.

A one-meter rise in sea level could erode 145 km^2 and inundate 71.5 km^2 of wetlands. Nearly half (71.5 km) of the coast is developed. Even for a 0.5-meter rise in sea level, the protection costs would be $215 million, or about 20 percent of GNP. Under a one-meter rise in sea level, protection may not be possible, forcing a combination of retreat and accommodation. Implementation of coastal zone management approaches to deal with existing problems, as well as climate change is strongly recommended.

Brazil

Brazil has 7,400 km of coastline extending from latitude 4^o North to 34^o South, with climates ranging from tropical to sub-tropical. Over the last 5,000 years, sea level has fallen along the Brazilian coast, based on geological records. However, this long-term trend is not found in tide gauge records and sea level rise has been measured at a number of tide gauges along the Brazilian coast over the last few decades.

About 30 million people, or 20 percent of the population live in the coastal zone. Much of the coastline remains relatively uninhabited: in 1991, 45 percent of the coastline was sparsely inhabited. Most coastal development is concentrated around 14 coastal cities, most particularly, Rio de Janeiro and Recife. These areas are vulnerable to sea level rise and require more study.

Cuba

Cuba is the largest island in the Caribbean being about 100 km wide by 1,100 km long. It is estimated that as many as 1.3 million people may live in towns and cities vulnerable to a one-meter rise in sea level, although the actual population vulnerable to sea-level rise is probably much lower. Vulnerable areas include 43 urban settlements and 62 rural settlements. This excludes Havana City which is generally located above these elevations. The role of tropical and extra-tropical storms is very important in terms of flooding potential. The low-lying south western part of the island is most vulnerable to such flooding. Management strategies are being suggested, such as prohibiting building in low-lying areas. Further assessment of the vulnerability of Cuba to sea level rise continues.

England and Wales

The coastline of England and Wales is some 4,200 km long and very varied. Land below the 5 m contour is estimated to have a population of 2.5 to 3 million (>4% of the national population) and generate about 6% of GDP ($30,000 million/year). Some 300 km of flood defenses provide flood protection to urban land with an additional 960 km of defenses protecting mainly rural and agricultural areas. The coast is also important ecologically providing internationally important habitat for many species. Three case studies were conducted in East Anglia, on the Central South Coast and a Coastal Habitat Study.

East Anglia is one of the more vulnerable parts of England and Wales, with many areas of low-lying land, both immediately adjacent to the coast and inland on the Norfolk Broads, as well as eroding cliffs. Coastal and river defenses, mainly built after the destructive 1953 storm surge are an integral part of the shoreline and its uses. This analysis (and the South Coast study, below) departed from the Common Methodology and utilized a cost-benefit framework and a common time frame of

2050. Assuming a global sea level rise of 40 cm by this time, protection was always the best response option (present value of damage of $270 million versus present value of full protection of $170 million).

However, at the scale of coastal management - the 113 flood compartments in the study area - retreat is the best response in 17 percent of the compartments even considering the lowest scenario - a global 10 cm rise in sea level. This shows that the scale of study is highly significant and practically speaking, a variety of responses are best employed within a national or regional coastal zone. The greatest uncertainty in the analysis was found to be the socio-economic factors, rather than the physical factors.

The Central South Coast of England is less physically vulnerable than East Anglia. However, the existing assets at risk are large being US $5,550 to $8,550, depending on the assumptions on valuation. These values are dominated by residential property which is over 60% of the value, while agriculture land is a relatively small proportion, being less than 1%.

Scaling this experience to all of England and Wales, it suggests a conservative and somewhat speculative present value of damage due to a 40 cm global rise in sea level of $6,000 to $7,500 million. In terms of likely response costs, they equate to present national spending on coastal defenses of about $300 million/year. This demonstrates that anticipated rates of sea-level rise will not dominant coastal defence and coastal management policy. Current efforts in developing shoreline management plans, including identifying coastal cells, will provide a better basis for furthering understanding of the problems of sea-level rise in a regional and national context.

France--Rochefort sur Mer

Located on the western coast of France, Rochefort sur Mer covers a region of 650 km^2 consisting of several marshes that were formerly part of a bay. The region's principal economic activities include agriculture, oyster farming, trade and industry, and tourism.

As a low-lying area, Rochefort sur Mer is subject to several floods a year. A 0.5-meter rise in sea level would threaten marshes (365 km^2), the industrial area, an aeronaval base, the harbors, and the low-lying districts of the town of Rochefort (total area: 1,150 hectares). The national park of Saint Yves would also be at risk (193 hectares). The increase in flooding resulting from such a rise is estimated to cause $31.6 million in damages within the developed areas.

Not responding to sea level rise would cost about 2,500 jobs and $12.5 million in annual revenues from the tourist industry alone. Rochefort has the resources to implement the recommended response strategies over the next century, which will cost $130 million. These strategies involve constructing dams, raising existing locks, installing pumps, building seawalls, nourishing beaches, and converting marshes for oyster farming.

Germany

The total length of the German coast is about 3,300 km, including all islands and major estuaries. It comprises 1,300 km on the North Sea and 2,000 km on the Baltic. The North Sea coast is low-lying with tidal flats, estuaries and fringing, mainly barrier islands. The area experiences significant surges and there is a long history of floods. The last major flood in 1962 caused a major upgrade of the coastal dikes, and 90% of the coast presently has flood protection. However, sea level rise is progressively increasing the risk of flooding, including parts of the large cities of Hamburg and Bremen. Action to increase the protection costs Hamburg is already required, while more widespread upgrading may be required by 2030. The Baltic coast is less low-lying and has more natural areas. Flooding is already a problem in certain areas, including cities such as Kiel. Protection of cities may cost $1 to $2 billion on the North Sea, and up to $5 billion on the Baltic. In the longer-term, nature conservation and ecological policy considerations are likely to favor an important areas protection strategy over a complete protection strategy. Such an approach would give room for some dynamic coastal system adaptation to sea-level rise, such as a along the Wadden Sea. In addition there is a need to adapt existing CZM institutions in Germany so that they are more aware of the possible problems of sea level rise.

Further analysis of vulnerability continues.

Ghana

Ghana has the longest sea level record in Africa, starting in 1925. It shows that sea level rise is already occurring at rates consistent with global estimates.

The low-lying coastal zone has extensive saltwater, brackish and freshwater marshes, as well as mangroves. Accelerated sea level rise will cause important changes including inland migration of wetlands and losses of existing wetlands. Cutting of mangroves and reduced sediment input due to the damming of rivers would exacerbate these losses. There are also sandy shorelines and the beginnings of an international tourist industry. The beaches are expected to erode and this would threaten historic forts and castles.

Only 11 percent of the Ghanaian coast is presently developed, so there is a great opportunity for anticipatory action for sea level rise. Future growth is expected to be rapid, so land use policies which allow for shoreline recession and wetland migration should be encouraged.

Japan

Comprising a series of densely populated islands with extensive mountainous areas (72% of the land area), Japan is heavily orientated towards the coast. At the same time these coastal areas are subjected to severe coastal hazards, particularly flooding and typhoon-induced storm surge and tsunamis. In addition, human-induced subsidence of low-lying coastal areas has been a widespread problem, with up to 4 meters subsidence in the worst case! (The subsidence is now under control). In total, over 9,000 km (or 27%) of the coast is already protected in some manner, including areas which have been subject to subsidence.

Presently over 2 million people live beneath high water, while a further 9.7 million people live in the area vulnerable to coastal flooding. If sea level rose one meter, the population below high water would increase to 4.1 million people, while a further 11.3 million people would live in the flood hazard zone.

The cost of elevating existing coastal protection and upgrading ports and harbors, by contrast, would be at least $200 billion. However, total reliance on protection would eliminate the remaining natural shorelines. To ensure a proper balance between development and the protection of whole populations the preservation of natural shorelines, Japan should incorporate sea level rise into both design standards and land-use planning.

Malaysia

Four potential impacts of sea level rise on the Malaysian coast were investigated: (1) inundation and increased flooding, (2) coastal erosion, (3) wetland loss, and (4) saline intrusion. Coastal erosion appears to be the most severe impact, with further aggravation of the existing erosion problems. While a quantitative assessment of erosion on the mud coasts in Malaysia is beyond existing knowledge, the nature of the impacts is expected to be severe. Destruction of coastal bands could inundate 1,000 km^2 of agricultural land. The mangrove forests with an area of about 6,000 km^2 (in 1990) could also be inundated, while landward migration of the mangroves is often prevented by shore development and erosion control structures. However, the mangrove forest is disappearing very rapidly due to reclamation; should the present rate of reclamation continue unabated, most of the mangrove forest may disappear within a decade. Saline intrusion will probably not be a significant problem due to an existing shift towards reservoir systems for water supply. However, the increasing management of rivers will reduce sediment supply to the coast.

Given the long lead times required to transform a policy into reality, careful planning for sea-level rise is prudent. A careful reassessment of the rationale and feasibility of existing and planned projects in the coastal zone is suggested in the light of sea-level rise in order that the limited resources are used wisely.

Mexico - Rio Lagartos, Yucatán

Separated from the sea by a sandy barrier, this special biosphere reserve contains four settlements of about 4,600 people and hosts the only nesting place of the Caribbean flamingo. The reserve's main economic activities are fishing, salt mining, agriculture, and tourism.

A one-meter rise in sea level could claim 6.6 km^2 of the reserve's sandy barrier, thus weakening its protective capacity. It would also disrupt the reserve's highly diversified natural habitats through salt-water intrusion. Guarding against these effects would require an investment of $5 million for new seawalls to protect the barrier island, and an additional $0.5 million to reinforce the existing 3 km of walls. Other proposed protective measures include stabilizing the sand dunes and reinforcing the existing walls enclosing the salt ponds.

Nicaragua

Nicaragua has about 805 km of coastline: 350 km on the Pacific and 500 km on the Caribbean. In addition there are extensive coral reefs estimated to cover 1,000 km^2. The coast is relatively undeveloped compared to the hinterland and based on the existing pattern and level of development. A semi-quantitative analysis suggests that given a one-meter rise in sea level, about 30,000 people (or 0.7% of the national population) would be subject to annual flooding. In broader terms fisheries appear vulnerable as sea level rise would effect critical areas of mangroves covering 150 to 600 km^2. Given present patterns of development the mangroves could migrate inland as sea level rises and maintain the fisheries.

Therefore, human development could be a critical factor in the maintenance of fishery resources. This habitat may be critical in a regional sense. Efforts continue to develop integrated coastal zone management.

Peru

In terms of infrastructure and population, a one-meter rise in sea level would affect only a small portion of Peru's coastline. However, many ports could be seriously affected and would have to be redesigned to the new water levels. In addition, wave heights during severe storms would increase along the coast, exacerbating existing problems of erosion. Most of Peru's coastal towns have been developed without any type of protective measures against a possible rise in sea level. Thus, a one-meter rise in sea level would permanently inundate the low-lying areas of Chucuito y La Punta, Pisco, and Ilo.

Poland

About 1 percent of Poland's total land area, 0.6 percent of its population (235,000 people), and a corresponding percentage of its GDP are in the country's coastal zone. Coastal urbanization is on the rise because of expanding demand for trade and harbor facilities, for exploration of offshore oil fields, and for tourism and recreation.

A one-meter rise in sea level would increase by a factor of 10 the annual risk of flooding in Poland's highly productive deltaic areas and would triple the rate of erosion of its sandy beaches, dunes, and barriers. Without additional protection, a one-meter rise would inundate 1,500 km^2 of agricultural land (mostly polders) once a year. This land has an estimated value of $3 billion. The highly valuable historic, cultural, and industrial centers of Szczecin and Gdansk, which cover 25 km^2, would also be threatened with annual flooding, particularly their ports.

The recommended strategy would be to fully protect these assets by upgrading sea defenses, protecting existing polders, pumping, and abandoning less valuable segments of the coast. This would cost about $1.5 billion over a century for a one-meter rise without development; with development, the cost would increase many times over. Poland’s GDP is estimated to be $100 billion (10,000 zlotys = 1 U.S. dollar).

Senegal

Human activities are strongly focused towards the coast of Senegal. More than half of the national population (4 million people) and 90 percent of its industry (including its entire international tourist industry) are concentrated in the coastal zone, mainly along about 70 km of the country's 500 km of wave-exposed coastline. A one-meter rise in sea level would inundate over 6,000 km^2 of land, most of which is wetlands. However, erosion would cause the biggest problem, threatening structures valued at $499-707 million (or 12 to 17 percent of Senegal's 1990 GNP) and displacing 110,000-

180,000 people. The tourist industry appears particularly vulnerable to sea-level rise - a rise of 0.5 meters would destroy most tourist infrastructure.

Protecting the developed areas would cost $255-845 million, mainly for beach nourishment to protect tourist infrastructure and maintain the associated beaches. Assuming that this investment occurred over 50 years (2051 to 2100), it would represent an annual cost of 0.7 to 2.2 percent of the national gross investment in 1990. Adaptive responses to minimize the country's future vulnerability to sea level rise include requiring building setbacks, particularly for future tourist resorts. Development could also be encouraged within the hinterland to help reverse existing patterns of coastward migration.

Turkmenistan

Over the last 2,000 years the height of the Caspian Sea has varied by 25 to 35 meters. Changes continue: from 1900 to the 1970's the Sea fell 3.4 meters. In this time period, some of the former seabed was developed. However, since the 1970's the water level has risen 1.8 meters threatening much of the new construction. There is a need for international cooperation of nations around the Caspian, including efforts to better predict the future elevation of the Sea.

United States of America

A one-meter rise in sea level would inundate/erode 16,900 km^2 of dry land, while another 17,000 km^2 of wetlands would be lost, mainly along the Atlantic and Gulf coasts. Flood risks would increase for 6.8 million households in coastal flood plains, doubling the costs of federal flood insurance. The environmental and economic implications are monumental, especially for the Mississippi delta, which lost about 50 km^2 per year throughout the 1980s.

The cost of protecting the 2,000 km^2 of densely developed coastal lowlands from a one meter rise would be $200-500 billion, or 0.10 to 0.25 percent of the nation's GDP. This protection would increase loss of coastal wetlands by about 1,000 km^2. In contrast, the cost of a retreat would be somewhat greater, $300-900 billion. Of the 36 coastal states, 29 participate in coastal management, and most of them have adaptive policies. The federal Coastal Zone Management Act encourages coastal states to anticipate and plan for sea level rise and provides funds for accomplishing this goal.

Uruguay

Sandy beaches comprise about 65 percent of Uruguay's coast. Every summer, the country's coastal resorts attract more than 1 million overseas visitors and earn $200 million in revenue. Domestic use of the beaches is also high. Only 71 km^2 of dryland and 23 km^2 of wetlands are threatened by a one-meter rise in sea level. However, such losses would have serious consequences for the tourist industry and change what is an important part of the Uruguayan national character - summer at the beach.

Nourishing 84 km of the shoreline is proposed as the most appropriate method of maintaining the beaches and tourist infrastructure against a one-meter rise in sea level. However, this would be extremely costly -up to $3.8 billion. If it is assumed that this investment would occur uniformly over 50 years (2051 to 2100), this represents annual expenditures of up to 7.7 percent of the gross national investment in 1990 on coastal protection. While future gross investment is uncertain, this suggests that sea level rise may place a higher burden on Uruguay than many other countries where VA studies have been completed. It is also unclear if sufficient sources of sand are available.

Uruguay has recently initiated coastal policies which requires new buildings to be set back 250 meters from the shoreline. The primary purpose is to preserve the coastal zone for the nation, but this will also reduce vulnerability to erosion and sea level rise. This forms an excellent basis to begin moves towards integrated coastal zone management and minimizing future vulnerability to climate change.

Venezuela

A one-meter rise in sea level could result in the loss of 5,600 km^2 of land along the Venezuelan coastline. This includes the possible inundation of Venezuela's sedimentary low-lying coastal plains and deltas, including the Orinoco delta. Uncertainty about sediment supply in the river makes prediction difficult. Increased erosion could impact several urban areas, which are particularly vulnerable as they are built adjacent to the shore with no setback. Sensitive ecosystems related to the fishing and tourist industry, such as mangroves and coral reefs, could be seriously degraded. Lastly, the vital oil and associated port industries could be adversely impacted as it is largely coast-based.

Nourishing recreational beaches and constructing seawalls along the 200 km of coastal areas which are developed could cost $1.5 billion. Assuming that this investment would occur over 50 years (2051 to 2100), this represents annual expenditures of 0.7 percent of Venezuela's gross national investment in 1990.

It is recommended that Venezuela develop an integrated coastal zone management plan. Only 385 km (or 13 percent) of the coastline is presently used intensively, offering a great opportunity for anticipatory adaptation to climate change.